DOCUMENT RESUME

ED 323 110 SE 051 570

AUTHOR Hart, E. Paul
TITLE Science for Saskatchewan Schools: A Review of Research Literature, Analysis, and Recommendations. SIDRU Research Report No. 7.
INSTITUTION Regina Univ. (Saskatchewan). Saskatchewan Instructional Development and Research Unit.
SPONS AGENCY Saskatchewan Dept. of Education, Regina.
REPORT NO ISBN-0-7731-0125-X ISSN-0835-6580
PUB DATE Dec 87
NOTE 210p.; Several pages of charts contain small and broken type which may not reproduce well.
AVAILABLE FROM Saskatchewan Instructional Development and Research Unit, Faculty of Education, University of Regina, Regina, Saskatchewan, Canada S4S OA2 ($15.00 plus $1.50 mailing and handling--Canadian dollars; 10% discount if five or more copies are ordered).
PUB TYPE Information Analyses (070) -- Reports - Descriptive (141)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Cultural Differences; Curriculum Design; *Curriculum Development; Curriculum Evaluation; Educational Improvement; Educational Strategies; Educational Trends; *Elementary School Science; Elementary Secondary Education; Environmental Influences; Evaluation Methods; *Foreign Countries; Individual Differences; Literature Reviews; Postsecondary Education; Science and Society; Science Curriculum; *Science Education; Scientific Literacy; *Secondary School Science; Technology
IDENTIFIERS *Saskatchewan

ABSTRACT

In 1981, Saskatchewan Education initiated a complete review of education in Saskatchewan. As a result of this review, the development of policies based on the concept of a core curriculum was recommended. In 1986, the report of the Core Curriculum Advisory Committee proposed a K-12 policy framework for Saskatchewan schools. In addition to a set of common essential learnings derived from the goals of education, several required areas of study were recommended as part of the core curriculum. Science education was one such designated area. This background paper was intended to provide guidance for curriculum development and implementation in science education and to anticipate social and educational change in order to create appropriate guidelines for future curriculum development. This thinking of science educators concerning future directions for science teaching in terms of the following: philosophical viewpoints, goals of science education, structure of science education, subject matter, learning experiences, instructional strategies, learning environment, individual differences, cultural differences, relationships with other subjects, relationships with general education goals and common essential learnings, evaluation methods, support systems, and postsecondary articulation. Appendices include position papers, frameworks, evaluation techniques, and guides from various other sources. A list of over 500 references is provided. (KR)

ED323110

SASKATCHEWAN INSTRUCTIONAL DEVELOPMENT & RESEARCH UNIT

SCIENCE FOR SASKATCHEWAN SCHOOLS: A REVIEW OF RESEARCH LITERATURE, ANALYSIS, AND RECOMMENDATIONS

Researcher/Writer:
E.P. Hart, Ph.D.

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY
E. Paul Hart

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
✓ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

SIDRU Research Report No. 7
December 1987

SE 051 570

BEST COPY AVAILABLE

Faculty of Education, University of Regina, Regina, Sask. S4S 0A2

SCIENCE FOR SASKATCHEWAN SCHOOLS: A REVIEW OF RESEARCH LITERATURE, ANALYSIS, AND RECOMMENDATIONS

Prepared for the
Saskatchewan Instructional Development
and Research Unit

With Funding from the
Saskatchewan Department of Education

by
E.P. Hart, Ph.D.
December 1987

Published 1987 by the Saskatchewan Instructional Development and Research Unit with funding assistance from Saskatchewan Department of Education. Publication does not constitute endorsement of the findings or opinions by either of these agencies.

Permission to reproduce or transmit any part of this report must be obtained in advance in writing from the Saskatchewan Instructional Development and Research Unit, University of Regina, Regina, Saskatchewan, Canada S4S 0A2.

ISBN 0-7731-0125-X

ISSN 0835-6580

SIDRU Research Report No. 7

Table of Contents

INTRODUCTION 1

Background 1

- Historical Perspective 3
- Large-Scale Status Study Research 4
- Recent Large-Scale Research in Canadian Science Education . . . 6
- Proposed Solutions to Problems in Science Education 7
- Summary 12

Curriculum Foundations 13

- Underlying Theories of Knowledge and Curriculum in Science Education 13
- Relationship of Science Education to the Core Curriculum 20
- Science Curricula in Saskatchewan 22
  - Elementary Science (K-6) 23
  - Intermediate Science (7-10) 23
  - Secondary Science (11 and 12) 24
- Summary 25

IMPLICATIONS FOR THE SCIENCE CURRICULUM FROM CURRENT RESEARCH 26

Philosophy 33

- Nature of Science 33
- Teacher Education 34
- Science-Technology-Society-Environment 34
- Science and the Learner 35

Goals of Science Education 37

Instructional Strategies 43

Evaluation 49

- Student Evaluation 49
- Program Evaluation 53
- Teacher Evaluation 53

Science and Technology-Related Societal and Environmental Issues . . 54

Integration of Science and Other School Subjects 58

Science and Related Areas 63
Implications for Teacher Education 68
Individual Needs 74
Relationship of Goals of Science Education to Goals of Education and Common Essential Learnings 78
CONCLUSIONS AND RECOMMENDATIONS 82
Curriculum Resources 83
Curriculum Leadership 92
Human Resources 95
Instructional Resources 96
External Resources 97
Research Resources 98
CONCLUSION 98

BIBLIOGRAPHY 100

APPENDIXES 137

INTRODUCTION

Background

In 1981, Saskatchewan Education initiated a complete review of education in Saskatchewan. As a result of this review the "Directions" report recommended development of program policy based on the concept of a core curriculum. In 1986, the report of the Core Curriculum Advisory Committee proposed a K-12 policy framework for Saskatchewan schools. In addition to a set of common essential learnings derived from the goals of education, several required areas of study were recommended as part of the core curriculum. Science education was one such designated area.

Changes in society and technology have forced a rethinking of what is "basic" in education and new goals have been designed to reflect a concern with the future (Saskatchewan Education, 1986). In the spirit of this statement from the Core Curriculum Advisory Committee, Saskatchewan Education commissioned a series of policy documents related to common essential learning categories and required areas of study. This policy paper on science education will review the field of science education, analyze options, and recommend policy for general discussion among educators and the public.

A single policy document in science education cannot provide all the answers to questions concerning school science programs. However, curriculum development cannot proceed in a vacuum. A starting point is required--an initial proposal, based on current research and discussion by informed theorists and practitioners. This policy statement is intended to provide a framework for policy discussion. It is intended to facilitate communication among all those individuals and groups in the field of science education who will have responsibility for developing, implementing, evaluating, and changing the science curriculum during the late 1980s.

Discussion about future directions for science education should be wide ranging and should not be unnecessarily restricted by categories. However, categories can provide a means for focussing discussions and for organizing the key issues under debate. This document includes sections which synthesize research literature and the thinking of science educators concerning future directions for science teaching in terms of the following: philosophical viewpoints, goals, structure, subject matter, learning experiences, instructional strategies, learning environment, individual differences, cultural differences, relationships with other subjects, relationships with general education goals and common essential learnings, evaluation methods, support systems, and postsecondary articulation.

Within the context of science education this paper will attempt to address contemporary concerns that question the manner by which science is taught in the schools of Saskatchewan, Canada, and other countries worldwide. Why do many children hate science? Why do science assessments indicate that children appear to be learning very little from school science at all levels? What do we know about science learning and instruction? What does recent research say about how children learn science? How can we improve science teaching?

There are no easy answers for these or many other questions concerning the state of school science. In order to adequately respond to these questions, an examination of current thought and research in science education should be used to develop proposals which can be reality tested "in situ." The purpose of this paper is to attempt to provide a foundation for renewal of science programs in Saskatchewan schools.

The generation of foundational reviews of the literature in an area like science education is somewhat like the purchase of a new computer--if you wait until next week, next month, or next year a new and better model will undoubtedly be available. This reasoning could result in indefinitely delaying a decision. In school science decisions must be made, however inadequate. The public demands that children be equipped to function effectively in a democratic society that is increasingly dependent upon science and technology.

This background paper is intended to provide guidance for curriculum development and implementation in science education. In order to provide a sound basis for curriculum renewal the following components of science education were examined: consideration of the strengths and weaknesses of existing programs; recommendations for improvement in school science by key educational stakeholders in Saskatchewan, Canada, the United States, Great Britain, and Australia; and a thorough review of the literature of science education. This science background document attempts to anticipate educational and social change in order to create appropriate guidelines for future curriculum development. Some healthy discussion of issues and beliefs is anticipated before the actual process of curriculum development occurs.

Other documents to be developed as a prerequisite to curriculum development in science education include the following: a K-12 framework for science in Saskatchewan schools, recommendations for a field study, and a long-term plan for curriculum development. Interest groups concerned with education in Saskatchewan and those whose primary focus is science education have a history of positive collaboration and cooperation. The science education study is intended to provide some concrete means to stimulate discussion and debate.

Historical Perspective

Given the turmoil that exists in science education in the mid-1980s, it seems important to describe the context within which this science background paper was formulated. Science education in Saskatchewan undoubtedly has unique features, but in general terms these cannot be considered in isolation from policies and practices of science education in Canadian, North American, and global contexts. Thus, what follows represents an attempt to characterize science practice in Saskatchewan schools within a global perspective, which includes a brief examination of historical developments and current reform issues in science education.

Today's science programs largely reflect goals which began to emerge, by consensus, a quarter century ago (Anderson, 1983b). Until the 1950s, although changing socioeconomic conditions and scientific developments had indirect impa .s, certain universities and colleges in the United States exerted the major emphasis on school science curricula for North America and influenced science education worldwide. Science was taught directly from textbooks as a series of facts to be memorized and repeated on tests of knowledge recall--a rhetoric of conclusions. Although some attempts at nature study were evident in elementary schools, where science was not generally taught, such efforts were typically textbook oriented. However, during the late 1950s, scholars from the various scientific disciplines began to exert a dominant force directing science education development.

Motivated by the North American desire to close ground on the Soviet Union's scientific advances, school science in the early 1960s was viewed as a means for increasing production of future scientists and engineers and improving public scientific literacy. Science was to be considered important as an intellectual pursuit in itself. Thus, a new emphasis appeared alongside knowledge acquisition in school science instruction--that of inquiry processes. The character of knowledge acquisition changed so that factual learning was subsumed under the rubric of broad conceptual schemes.

The traditional academic rationalist influence of natural scientists resulted in a structure of the disciplines approach popularized by Bruner and analyzed by Schwab. Designers of the National Science Foundation's large-scale curriculum projects [(e.g., Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS), Science--A Process Approach (S-APA), Biological Science Curriculum Study (BSCS), CHEM Study, and Physical Sciences Study Committee (PSSC)] were concerned with structure and the processes of science. By structure they meant the identification and ordering of concepts and conceptual themes extant in the disciplines. By processes of science they meant primary investigative techniques. Laboratory work was proposed as a major device for teaching these processes (Hurd & Rowe, 1964; Robinson, 1969). Thus, science in the schools of the 1960s was intended to be more theoretical and to give less attention to personal and technological applications. A major goal of these "alphabet curricula"

was to have students work as scientists work in order to understand science as a field of disciplined inquiry.

At about the same time as these "innovations" were being introduced in the United States, similar changes in science curricula were occurring in Great Britain, Europe, Australia, and subsequently, by diffusion and adoption, in many other countries of the world.

Change is inevitable. The rapidity with which the world today is changing, however, is a recent phenomenon. Many of these changes are the result of unprecedented developments in science and technology interlocking in a reciprocal fashion with social, political, economic, and cultural transformations. The changes are man made and there is a lack of understanding about their effect on humans and on the environment, whether these changes are controlled by or are controlling humans.

The complex interactions of scientific and technological advancement coupled with serious societal and environmental problems of the late 1960s and early 1970s, most with no apparent solution and with apparent ties to science and technology, resulted in a period of disillusionment with science (Anderson, 1983b). Social unrest, conflict, political problems, environmental concerns, and a loss of faith in science, education, and other central institutions of society created a climate of protest, questioning, and retrenchment. This led to a call for a return to former times, traditional values, and earlier priorities (Yager, 1982).

During this period of social and political problems, science education was attacked on several fronts. There was a challenge to the appropriateness of National Science Foundation science curricula; public concern about inclusion of sensitive areas such as evolution, sex, and social issues; lowered funding of inservice; and suspension of teacher training activities. Creative and thoughtful as curriculum projects of this period were, for most students science education in the late 1960s and 1970s consisted of minimal exposure in elementary school, "forced" exposure to junior high school science, and completion of only one high school science course, typically biology. Criticisms about these science courses from teachers, from students, and, more recently, from parents have been devastating (Mayer, 1979). As a result of these criticisms and because of declines in science SAT scores, the National Science Foundation funded several major studies in an attempt to identify the details of the crisis in science education and to suggest remedies.

Large-Scale Status Study Research

Initially, three major studies were funded by the National Science Foundation in 1977: a comprehensive literature review on science education, 1955-75 (Helgeson, Blosser, & Howe, 1977); a national survey of practitioners concerning materials, practices, and leadership in science education (Weiss, 1978); and a set of case

studies and in-depth analyses of a variety of representational school systems (Stake & Easley, 1978). The National Science Foundation then contracted with nine professional organizations (including the American Association for the Advancement of Science, the Association for Supervision and Curriculum Development, the National Research Council, and the National Science Teachers Association) to review these three status studies and to report on the significance of the studies from the unique perspective of each organization. The National Science Teachers Association (1978b) also completed a science education study which was subsequently analyzed into position statements of status, goals, and accomplishments. Science education leaders reacted to the analysis and provided recommendations for resolving current problems (Yager, 1981a).

In an attempt to synthesize the results of these comprehensive studies as well as the science component of the Third Assessment of Science for the National Assessment of Educational Progress (1979), Project Synthesis was initiated. A discrepancy model of the actual and desired states of science teaching in biology, physical science, inquiry, science-technology-society, and elementary science was developed. The actual state of science education was defined through analysis of information from the four major studies. A synthesis of social indicator reports, symposium reports, reports of futurist groups, editorials, and funding programs as well as the major study reports defined the desired state of science education. An analysis of discrepancies between actual and desired states resulted in specific recommendations for future action (Harms & Yager, 1981).

Project Synthesis used a set of broad goal clusters related to personal, social, academic, and career awareness needs to provide a framework for discussion of major emphases in science education. It is noteworthy that only those goals related to academic preparation were found to be receiving significant emphasis in science education. Given these results, it is not surprising that Project Synthesis called for a new conceptualization of the science curriculum to meet new goals.

A summary of over 5000 pages of data produced during the science education assessment period resulted from Project Synthesis. The following statements illustrate the magnitude of the problem that was identified in school science programs: knowledge of basic science concepts is very low and no growth in understanding of science concepts or interest in science can be demonstrated over four years of high school; science is viewed as too difficult and not relevant; science is not taught in more than one-half of elementary school classrooms; students do not particularly like science and the dislike is acquired early; only 21% of eighth grade students have a positive attitude toward science courses and this percentage remains constant through high school; secondary school science programs can be characterized by one word--textbook--which determines content, order, examples, applications of content, and teaching strategy; more than one-half of recently employed science teachers do not meet minimal state requirements for the science subjects they teach; teachers have "faith" in textbooks--if only the right one can be found; classical lecture style teaching characterizes most classrooms; and teaching

science as inquiry, a goal stated in the 1960s, is rarely observed (Harms & Yager, 1981).

The new set of goals for science education proposed by Project Synthesis reflected a major shift in emphasis toward personal and societal goals. Desirable science programs should actively involve students in problem-solving tasks appropriate to the grade level. Problems should grow out of firsthand student experiences so that genuine alternatives can be explored, real decisions made, and the consequences of those decisions known. General science courses should emphasize topics relating to the effect of human activities on the world, human dependence on global environments, and human responsibility for environmental preservation. College preparatory courses should emphasize science-technology-society problems.

Although Canada tended to play a spectator role in science program development initiated in the United States, many American programs gained acceptance in Canada. For example, Saskatchewan was the first province to adopt PSSC physics in 1962. Most upper secondary science curricula are still based on modified versions of PSSC, BSCS, and CHEM Study (MacKeracher, 1985). However, the science curriculum at the upper secondary level is currently under revision in most provinces. At the lower secondary, intermediate, or middle years level, advances in learning theory and provincial science assessments have led to revised science programs often involving life, earth, and physical science courses in separate years. Saskatchewan adopted an activity-based curriculum with extensive guidelines at this level(Saskatchewan Education, 1979). At the elementary level, science courses evolved from nature study programs in the 1950s to conceptually based activity-oriented programs in the 1970s. Although provinces such as Saskatchewan developed unique activity-oriented curriculum guides in the early 1970s, most provinces in the 1980s, including Saskatchewan, rely increasingly on American designed courses such as Addison-Wesley's STEM program.

With the release of more comprehensive studies of science education in Canada, a descriptive data base was established for the purpose of policy development in Canadian science education (Science Council of Canada, 1984). Some serious problems in Canada's school science teaching were exposed. Although science teachers in Canada at the secondary level are, in general, experienced and hold university degrees, concern was expressed over their possible lack of currency in scientific knowledge and teaching methodologies. Elementary teachers tend to have little background in science and relatively little training in science teaching methodologies (Orpwood & Souque, 1984).

Recent Large-Scale Research in Canadian Science Education

In 1979, the Council of Ministers of Education published a comparative survey of science education in Canada through the Science Council of Canada. Although this report consisted largely of documented technical information from which

readers could draw their own conclusions, some definite trends in science education in Canada were briefly discussed. For example, the report described an increased emphasis on environmental studies at all grade levels. It noted a trend in provincial science curriculum guides toward the identification of core topics with flexibility in materials selection, local issue development, and meeting interests and needs of students. This report also described the central issue in science education today--the distinction between the view that science is a formal academic discipline and the view that science should be studied in terms of its role and significance in modern society. The former view emphasizes basic concepts and principles and inquiry experience; the latter view emphasizes contemporary topics in human biology, environmental studies, and technological societal applications (Haggerty & Hobbs, 1981).

In 1984, the Science Council of Canada published the results of a large-scale study of science education in Canada. Components of the study included the following: issues raised through a set of invited papers by critics of science education; findings of extensive research investigating the nature of science in Canadian schools; and suggestions for change arising from a series of deliberative conferences held in all Canadian provinces. Conference participation included representatives from ministries or departments of education, school trustees, school boards, teachers' federations, university scientists, engineers, science educators, business, labor, parents, and students. This deliberative inquiry study model differed substantively from the discrepancy model of Project Synthesis (Orpwood, 1985).

Although subject to some particularly cogent criticism (Fullan, 1984; Nadeau & Desautels, 1984), the report of the Science Council of Canada deserves careful attention by science educators, curriculum theorists, and policy makers. Despite differences in methodology between Canadian and American studies, some cross validation is apparent from the similarities of problems revealed and solutions proposed. Science in Canadian schools was seen as boring and irrelevant to many students, totally devoid of context to real science or the real world, nonexistent in more than one-half of all elementary school classes, and taught by elementary school teachers nearly three-quarters of whom had received no university level science in classrooms having no special facilities for science. The evidence from case studies and teacher surveys pointed to a significant gap between intentions for science and the practical realities of schooling (Science Council of Canada, 1984).

Proposed Solutions to Problems in Science Education

The Science Council of Canada study and Project Synthesis made recommendations to ameliorate the apparent negative impact that school science has on many students. These major recommendations are summarized as follows:

1. Science education should be provided for all children in all grades of elementary school.

2. Science should be taught at all levels of school with an emphasis on the relationships of science, technology, society, and environment in order to increase the scientific literacy of all citizens.

3. The view of science and technology presented to students should include social, historical, and philosophical dimensions (i.e., the societal and ethical consequences of modern science and technology).

4. Students with high ability or special interest in science and technology should have program provisions made which encourage and challenge them to further inquiry.

5. Science programs should emphasize the full use of human resources including those of women and minority groups.

6. Science should provide young people with opportunities to experience, with guidance, the sifting and weighing of both scientific evidence and public information as the basis for rational decision making.

7. Science education requires new goals because today's students will be operating as adults in a future society that will be even more technologically oriented and they will be participating as citizens in important science-related societal decisions. Almost total concern for future academic preparation, as is currently the case, is a limiting view of school science.

8. Science in schools must have goals balanced among academic preparation, personal needs (how individuals can use science and technology to improve their own lives and help them cope with a changing world), societal issues, and career awareness.

9. Assessment techniques must be developed and implemented for all the goals and objectives of science education (not simply content knowledge as is currently the case).

10. Science education in elementary and secondary schools should take into account local, regional, national (e.g., the Canadian reality), and global dimensions.

Many more specific recommendations (47 in the Science Council of Canada report) for implementing these major conclusions can be found in the report documents. These cover curriculum policy changes, teacher education, development

of curriculum resources, public support for science education, and required research.

It appears obvious that, if one has the inclination to make time available to look beyond the day-to-day demands of career, to do some professional reading or to attend conferences, sweeping changes are imminent in science education. Given the changes of the early 1960s, which attempted to redefine the direction of science education and which have had mixed results, some healthy skepticism is to be expected among practitioners who lived through the previous "revolution." What appears to be needed before proceeding with another shift in direction in science teaching is a mechanism through which one can view changing perspectives in some sort of meaningful context.

In 1985, the first volume of a comprehensive study of science education in Canada, part of the Second International Science Study of the International Association for the Evaluation of Educational Achievement, was published. The study was largely undertaken by science educators in Canadian universities who focussed on policies, practices, and perceptions for curricular reform and school improvement. The study was significant in that it documented Canadian history of reform in curriculum materials and practices that paralleled the reform movements in the United States and Great Britain (Connelly, 1985). This study in combination with the Science Council of Canada study includes information on actual practices in science education and provides a solid descriptive data base on which to underpin curriculum reform proposals. This unprecedented Canadian endeavor permits new policy development to directly address a major criticism of past curriculum reform efforts which is that policy formulation was initiated by centralized directives rather than on the evidential basis of actual practices (Schwab, 1983).

This ambitious study generated descriptive comparative knowledge of Canadian science curriculum policy and practice and integrated that knowledge with the results of the Science Council of Canada study thereby providing a theoretical underpinning, a model, and descriptive data for science education policy formulation, curriculum reform, and experimental and ethnographic research. In addition, a study of teacher education in faculties of education across the country was integrated into the report.

The methodology for the International Association for Evaluational Achievement study, characterized as entrepreneurial crisis research after Enns (1982), was a meaningful contribution to the literature on curriculum research method because it provided a framework which helped to conceptualize the necessary prerequisites to policy formulation for science education in Saskatchewan schools. For example, the procedures followed by Saskatchewan Education whereby consultants were used to develop position papers, which were subsequently validated by deliberative teams of stakeholders, were recommended by the research team of this study. General findings of this study were difficult to summarize because of

their descriptive nature. Thus, only those points relevant to policy proposals for science education in Saskatchewan were summarized for purposes of this paper.

Comprehensive statements on the aims of science education, as distinct from the objectives of science courses, are provided by only two provinces, Alberta and Newfoundland. In Saskatchewan, direction for science curricula are provided by curriculum guides for Divisions I and II (1971), Division III (1979), Science 10 (1980), and separate guides for grades 11 and 12 biology (1971), chemistry (1976), and physics (1976). Saskatchewan was characterized by MacKeracher and Jantzi (1985) as having a textbook-based biology curriculum, a content-based chemistry curriculum, objective-based physics, Science 10, and Division III curricula, and an activity-based Division I and II science curriculum. Aims of science education inferred from analysis of these documents were developed in a summary of the Science Council of Canada study (Orpwood & Souque, 1984). These curricular outcome statements will be examined in the goals section of this report in conjunction with implementation differences among science goal statements across curriculum levels.

In summary, MacKeracher and Jantzi (1985) discuss the difficulties involved in document analysis given the diversity of type and nature. In spite of this quantity and variety of documents that describe policies and outcomes, there was a high degree of similarity in the general outcomes of science curricula among the provinces and territories of Canada.

Detailed analysis of the content of science curricula in Canadian provinces (Finegold & MacKeracher, 1985) provides data which complement and expand the only other science curriculum asessments ever attempted in Canada, the Canadian Ministers of Education Council study (Haggerty & Hobbs, 1981), and the Science Council of Canada study (Orpwood & Souque, 1984). Not only are secondary analyses and interpretations of interprovincial Canadian data possible but, within the International Association for Educational Achievement study, worldwide comparisons of science curricula can be conducted. Eventually, relationships among intended, translated, and achieved science curricula may be examined. This will be useful to science educators in Canada where curriculum practices tend to separate curriculum policy development at the provincial level (curriculum intention) from curriculum policy implementation at the board, school, and classroom level (curriculum translation). The translated curriculum is conceptualized as both teacher perceptions, beliefs, and opinions about science curriculum and science teaching and teachers' actual practices in their classrooms.

Results of the content analysis of science curricula will be discussed in a subsequent document dealing with scope and sequence. However, it is useful to know what analyses of the four science disciplines indicated in terms of cross-country commonality. The common curriculum is more extensive in chemistry than physics at the upper secondary level, more extensive in physics than chemistry at the lower secondary level, least extensive in biology at all levels, and nonexistent

in earth sciences (Finegold & MacKeracher, 1985). The apparent lack of commonality in the biology curriculum probably would not have been so marked if the analysis had been based on conceptual schemes.

Environmental education topics and courses are popular across Canada. Prince Edward Island science curricula contain the greatest number of environmental topics. Studies of the environment are viewed as providing the basis for the following: topics or units of study which integrate concepts from several science disciplines, inclusion of Canadian content in the curriculum, and discussion of societal issues that lend themselves to examination of the practical application of scientific principles.

Finegold and MacKeracher (1985) indicate that the current science curriculum in Saskatchewan appears to present a special case, without clear explanation. Two possible reasons are given for this exceptionality. First, science curriculum guides were developed by separate committees, each of which worked from its own particular conception of what science should be like within each curriculum level and each discipline. Secondly, when Saskatchewan Education revised the elementary science curriculum in 1970-72, the main thrust was to alter the way science was taught. Their goal was to make science a hands-on learning experience with emphasis on processes. Most of the material provided for teachers was written into the activities section and descriptions of concepts were brief. Thus, there appeared to be little opportunity for K-12 science program development.

In another section of the International Association for Educational Achievement study, Crocker and Banfield (1985) used both survey and policy-capturing techniques to examine science teacher perceptions. Given the marked influence that teachers exert in translation of curriculum, several contextual issues are relevant here. In general, Canadian teachers believe that they would not have to change their teaching style to accommodate a new setting or teaching scenario, whatever its specific characteristics, except in the case of low-ability and aptitude students. Teachers tended to favor the following: a curriculum which includes a student text, high-ability students, well-equipped schools, strong community support, and small group teaching (although this is inconsistent with prevailing teaching practice). The factor that most strongly influenced teacher judgment of a curriculum was its associated teaching methods. Somewhat strangely, the scientific basis (process, basic facts and concepts, technology, and society) did not significantly influence teacher judgment of curriculum acceptability.

The dominant form of instruction was teacher presentation. Teachers reported that, although they would reduce lecture and increase laboratory time, most other activities including seatwork, class discussion, and demonstration would remain the same under ideal conditions. There appears to be support for more teacher responsibility for defining objectives, selecting texts, and most other areas surveyed (selecting lesson materials, determining homework, evaluating achievement) except in areas such as course selection for students and discipline. Crocker

and Banfield (1985) concluded that some of these results reinforce intuitive impressions about science teaching in the schools.

Summary

The context within which educational policy is established must be carefully considered if curriculum development is to be meaningful. This introductory section on science education in Saskatchewan attempted to characterize some important aspects of current science practice in this province as they have evolved in a global, but primarily Canadian and North American, context. There appeared to be good reason for this delimitation. During the 1960s all Canadian educational jurisdictions bought, then selected from, the new American science curricula: PSSC, Harvard Project Physics, CHEM Study, BSCS, and STEM. In some provinces, including Saskatchewan, these programs are still in use. Whether a province develops its own science curricula, with appropriate content, activities, textbooks, learning resources, and teaching guides, or buys all or part of a curriculum already developed depends on several factors. One factor is the availability of usable curricula from other sources; the second factor is the availability of time, money, energy, and expertise (Connelly, Crocker, & Kass, 1985). Closely linked to these factors are matters of student assessment, teacher education, teacher inservice, and teacher translation of the intended curriculum. The research teams that were involved in both the Science Council of Canada study and the International Association for Educational Achievement study of science education in Canada are convinced that the teacher is the key link between what is intended and what is implemented and achieved by students. Thus, the recommendations of this document will be made after carefully considering teachers as well as curriculum in each of the categories that needs to be addressed in a comprehensive science education policy.

Within the Canadian and Saskatchewan contexts of past and present policy and curriculum development and implementation, a second foundation for new policy proposals in science education is that they are research based. Research findings in teaching and learning processes, development and sequencing of specific skills, organization of social systems, decision making, and other educational processes have increased the potential for solving educational problems. Although it is not appropriate to move some research results directly into practice, evidence accumulated into generalizations after careful scrutiny can be useful to classroom teachers. Knowledge generation has accelerated rapidly in the last ten years. Information synthesized from thousands of research studies must be considered when new science curricula are developed. The following sections of this background paper attempt to survey recent literature on science education research for information which can be useful to curriculum developers.

Given the time period allotted by Saskatchewan Education for completion of this background work, several delimitations had to be imposed on the review of

current thought and research. The science education topic categories to be reviewed were determined by curriculum branch personnel at Saskatchewan Education. Thus, it is likely that, given the expressed purpose of curriculum-relevant research, the total domain of science education, as defined by Welch (1985), could not be examined. This analysis was further restricted to secondary sources based on syntheses carried out by other researchers accessed through the ERIC system. Yearly reviews of research, meta-analyses, and summaries of current thought were used to distill a large number of science education articles. This necessitated that acknowledgement of the assumption of quality in the syntheses be added to the limitations imposed by the quality of the original studies.

Before examining research and literature that analyzes options and attempts to provide direction with respect to necessary components of a science curriculum, some theoretical grounding in curriculum foundations seems necessary. The next section will attempt to provide a broad curriculum perspective from which to conceptualize how science curricula might be generated.

Curriculum Foundations

Underlying Theories of Knowledge and Curriculum in Science Education

All curricular decisions are influenced by value positions that are based on implicit or explicit philosophical assumptions. Empirical knowledge may allow the prediction of factual outcomes of particular decisions, but the ultimate choice of action involves human values. Thus in making curricular decisions it is useful to attempt to make explicit underlying assumptions that govern the structure, pattern, or organization of curriculum alternatives, albeit briefly.

Science and scientific knowledge are grounded in the world of empirical reality. The scientific world view is predicated on the assumption that reality is inherent in the existing natural world. Ultimately, truth is discovered by scientifically examining the reality inherent in this world. This earth-centered ontology results in an empirical epistemology. However, science as a way of knowing cannot function independently of other world views even though it assumes a commitment to an earth-centered philosophy or belief superstructure.

Science education, given its roots in science, is governed by an epistemology of discovery in order to learn the laws of nature. Discovery is based on logic (as mathematics is exclusively and thus is often called a "pure" science) and sense perception (sensing, reasoning, seeking self-evident truths). However, as part of an evolving field of human education, science education must attend to alternative philosophies of education, which suggest that acquiring knowledge is a process of

construction of experience into a conception of the world, a man-centered ontology.

One important method of constructing knowledge, variously designated as the scientific method, reflective thinking, or critical thinking, represents a way of arriving at knowledge for decision-making purposes. The validity of knowledge produced this way can be verified, and because it is founded in experience it is regarded as tentative and subject to revision or rejection as a consequence of subsequent experience (see Zais, 1976).

A science curriculum based on an epistemology of constructed knowledge (a man-centered ontology) thus tends to emphasize the processes of learning that are required to construct the knowledge filtered through the world of experience.

The large-scale science curriculum revision projects at both elementary and secondary levels represented an attempt by educators such as Bruner and Schwab to broaden the epistemological base of school science by introducing active discovery epistomology to the predominant passive acceptance of knowledge on authority. This massive science curriculum effort resulted in programs such as BSCS biology, PSSC physics, and SCIS elementary science. It appears that these educational philosophers and curriculum theorists were attempting to provide school science with more consistent alignment between the earth-centered ontology of the sciences and the implied epistemology of discovery. Thus, in curriculum materials of the 1960s, there was increased emphasis on inquiry/discovery and learning processes employed by scientists.

What appears to be happening to science education in the 1980s is a continuation of attempts to broaden the epistemological base to include, more centrally, an epistemology of constructed knowledge based on a man-centered ontology. The implication for the curriculum is a shift in emphasis from a combination of knowledge acquisition and process development to the application of process to science-related societal problems. The focus shifts from simply "knowing that" to "knowing how" to learning how to solve real science-technology-society-environment problems. This extension of the science curriculum base now introduces values, morals, ethics, and aesthetics as legitimate components of the real or authentic world of science.

Essentially, this redirecting of science education in response to what has been described as a major crisis in the field is a response based on an epistemology of pragmatism. Historically, the new movement in science education is a reconsideration of the curricular applications of the progressive movement. Aims reflect an emphasis on individual growth coupled with democratic social competence. The curriculum maintains subject matter as an important component of course work but only as a basis for dealing reflectively with relevant individual/social problems. Students use subject matter as a basis for decisions but the focus is on societal, environmental, and technological problems in need of solution,

problems which directly relate to student experience locally or globally. Subject matter is selected on the criteria of student capacity to derive meaning from it and its usefulness in the process of problem solving that leads to decision making. Thus, the validity of the scientific mode is accepted on the assumptions that it addresses itself to certain aspects of human behavior in the sociocultural context and that other kinds of data are needed to produce a comprehensive conception of human-technology-society-environment relationships.

Curriculum aims, goals, and objectives imply "directions" for education. They are influenced by epistemology, society/culture, learning theory, and the individual. Currently, the most commonly used source of aims, goals, and objectives in science curricula is subject matter or, more accurately, the structure of the disciplines. The assumption of long-range professional expertise in the subject has tended to generate narrow, specialized objectives. Critics of contemporary school science curricula question the contribution of this kind of science to the general education of the lay citizen.

An argument for a structure of the disciplines approach to science generally assumes that the interconnected concepts and generalizations that constitute these bodies of knowledge have been validated as true and as rationally or logically organized to promote further discovery. This is a powerful argument if one considers subject matter by itself. Whether this approach is sufficient to meet the educational needs of individuals and societies is debatable and the subject of current science education theorizing.

The current argument in science education is that if people in society are to begin to make sense of their existence, it would appear that they need to be able to "think the world back together after they have learned to think it apart." This does not mean the integrity of the disciplines is at stake; it does mean that the role of the disciplines may change from content to resources for content. We can no longer assume that the learner will integrate this knowledge of the separate subjects unaided in a way that will permit personal and social competence. Development of constructs that enable conceptualization of meaning in one's life may demand organizational patterns based on different criteria. For example, relevant materials from chemistry, biology, political science, economics, and other disciplines must be organized and interrelated to understand acid rain. To move away from highly discipline-centered organization in school science requires rethinking of a magnitude that may defy curricular reality.

In addition to considerations of the logical organization of subject matter, where concepts and generalizations are organized rationally so that understanding of concepts such as matter, force, and energy leads to more complex explanations of the operations of the physical world, curricula must be organized in terms of the capabilities, understanding, interest, and restricted experience of the learner. Subject matter must account for the psychological organizational patterns of individual learners, that is, the concrete basis on which learning begins and the

manner in which it develops with age and experience. Science subject matter is sequenced to attempt to accommodate logical and psychological organization. The current curricula tend to emphasize the logic of the discipline, although the newest materials attempt to account for psychological theories that govern human learning. In school science the organizational principle governing the disciplines is that of simple to complex, from simple subsumed components to complex structures. Between levels, prerequisite learnings are often assumed. For example, life and physical science concepts at Division III are assumed to provide some basic conceptual information for more advanced study of biology, chemistry, and physics in Division IV. Recently, the learning theory of Piaget and his colleagues has caused a number of science educators to place more emphasis on what children are capable of learning than on what they should be learning at various stages of development. Considerable debate among learning theorists has resulted in general attempts to draw from each of the theories meaningful principles that make sense in terms of everyday experience.

Curriculum committees will obviously want to select subject matter and learning experiences that most effectively and efficiently bring about the realization of aims, goals, and objectives. Translation of goals into learning experiences involves making selection judgments. Criteria for inclusion or exclusion are usually made implicitly or explicitly on the basis of significance, utility, interest, and human development. Significance of content is usually judged on how essential or basic it is to the discipline. Basic concepts have been identified in each discipline of science viewed as essential (i.e., life, earth, and physical science areas). This criterion was influential in selection of concepts and processes in the discipline-centered curricula of the 1960s. Bruner (1960) popularized the idea that the fundamental structure of a discipline makes the discipline more comprehensible. This criterion tends to foster specialized competence and ignores the needs of learners and society.

In order to broaden this conceptualization of school science, a balance with the following criteria is desirable: utilitarian criteria can be used to maintain a relevant connection between curriculum and society; the inherent interest criterion considers the lives of children and the meanings inherent in their experience; and the criterion of human development implies consideration of the intimate connection between individual character and social context. The human development criterion attempts to account for what recent critics of the discipline-centered science curriculum believe has been ignored at their peril--the social values attached to the sciences. It attempts to focus inquiry into that content which impinges most significantly on the quality of human existence in contemporary society (see Zais, 1976).

Taba (1962) and other curriculum writers advocate the selection of learning experiences that provide for the attainment of multiple goals and objectives. The intention appears to minimize the probability of teaching that focusses narrowly on facts and content (see also Roberts, 1982). For example, curriculum committees

can consolidate into a single problem-solving project the following learning outcomes: (1)problem-solving skills such as problem formulation, hypothesizing, data gathering, data interpretation, perceiving relationships, developing generalizations, testing hypotheses, drawing conclusions, and communicating results;(2)group process skills such as awareness of group process, sensitivity to others, cooperative planning, division of labor, integration of effort, and democratic decision making; and(3)social attitudes such as positive dispositions toward cooperation, compromise, community, acceptance of others, and political processes. All of these outcomes can be attained while learners acquire personal meaning and competence, knowledge, and understanding from the science-related social or environmental issue under study. This type of activity encourages teacher selection of alternative instructional strategies and more varied and broadly conceived active forms of learning as opposed to tasks that focus mainly on the learning of content.

Learning activities that center on more passive modes of listening, reading, and writing tend to predominate in science classrooms today. This focus has resulted from an almost exclusive utilization of content goals as the criteria for selection of learning outcomes as well as a failure to recognize many undesirable process outcomes that follow from such activities. If a wide variety of desirable process goals are to be realized, it is important that teachers monitor all outcomes. This reasoning provided the basis for the development of the goal concept of scientific literacy in science education, that is, the conceptual basis of the school science curriculum.

Any examination of science curricula must also concern itself with the arrangement (in terms of structure, pattern, and organization) of the curriculum. Central criteria for curriculum design involve analysis of scope, sequence, continuity, and integration with respect to basic curriculum components--goals, content, learning experiences, and evaluation--as well as program support elements such as learning environments, teaching methods and roles, operating conditions, and research and development. The goal is internal consistency, that is, cohesiveness and coherence of the total K-12 science curriculum.

Three basic categories of curriculum design are subject-centered (disciplines), learner-centered (activity), and problem-centered (core) designs. Although perfect replicas of these prototypes are rarely encountered in practice, they provide a framework, based on underlying philosophical assumptions, for particular emphases in curriculum construction. For example, because subject-centered designs use content as the basis of curriculum structure, other curricular components (goals, activities, evaluation) have less impact on their organization. Content specialists have discovered the inherent nature of the organization of the discipline. Scope and sequence are determined by the logic of the subject matter. Instruction emphasizes lecture, discussion, exposition, explanation, recitation, questioning, written exercises, oral reports, and term papers. Content coverage is emphasized with the focus on memorization and acquisition of information.

Certain subjects constitute the general education component of the curriculum (i.e., English, social studies, mathematics). Fundamental assumptions that the inherent logic of the discipline corresponds to the human psychological process employed in learning it and that such organization facilitates storage and retrieval for future use in life situations (transfer) is being questioned by recent research. A subject/disciplines curriculum is comfortable for university-educated teachers with subject matter expertise. Textbooks follow this organization, parents support what they know and feel is "academically" sound, college entrance requirements emphasize traditional school subjects and a subject-centered curriculum is easy to administer and objective to evaluate.

However, the disciplines design tends to fragment knowledge. Concepts and facts are learned within disciplines with little opportunity to relate these ideas to anything that might give them perspective and meaning beyond "passing the test." The amount of coverage of a predetermined body of subject matter restricts the possibility of relating subjects to real-world personal and social issues so that many students either "tune out" or simply "play the game." The importance of beginning instruction on the student's own psychological ground is a well-established pedagogical principle. When external coercion is the prime motivator, students learn to despise the school, the subject, and the people who teach it. Organization of curriculum depends on purpose. Because learner purposes and subject-implied purposes are usually discrepant, learners may be alienated.

Although recent research in child development mitigates against the extremes of passive memorization of facts, data retention remains as a narrowly focussed central outcome of the subject-centered design. Clearly, in a highly complex technological society, it is insufficient education that simply fills youths' heads with a smorgasbord of information. Curriculum design must take into account the process goals of both cognitive and affective domains of learning. This includes thinking critically; accessing and analyzing information; selecting data; transferring facts, concepts, and generalizations to new and different situations; evaluating and critically assessing alternatives and conclusions; and involving feelings, values, and cultural heritage in decision making (Hurd, 1986).

The discipline-centered curricula of the 1960s such as SCIS, S-APA, BSCS, CHEM Study and PSSC attempted to move science teachers from a content focus to a process/concept focus. Both conceptual structure of the discipline and its mode of inquiry were to provide a more balanced approach to science teaching. Students were encouraged to see the structure of the discipline through inquiry and discovery. However, in spite of efforts to overcome intellectual passivity and preoccupation with facts, these new science programs, by virtue of the similarity of their organization to the traditional subjects, could not effect teacher implementation. What the vast majority of teachers of secondary science have done is to continue teaching content from the new texts and curriculum materials. Because science curricula remain detached from realities outside the school, their significance as educative vehicles is questionable (Stake & Easley, 1978; Science Council of

Canada, 1984). Bruner (1971), a former leader of the structure of the disciplines approach, now repudiates the disciplines design and favors a curriculum focussed on the context of the problems that face us.

Connelly et al. (1985) classify all science curricula above Division II as subject-based curricula. Biology is considered textbook based; chemistry is content based; and physics, science 10, and Division III science are objective based. In the sense that activity-based curricula are often grouped under learner-centered designs founded on man-centered philosophical thought, it would appear that the elementary science curriculum in Saskatchewan was intended as a concept/process based curriculum more consistent with the thinking associated with the National Science Foundation elementary science curriculum projects but without the expense and disadvantages of commercially prepared and distributed kits of materials. The point is debatable because the abstractness of the conceptual schemes and unfamiliarity of teachers with a process approach has tended to render some excellent activities ineffective. In essence, this curriculum is not used in Saskatchewan schools. Very few elementary teachers use the curriculum guide that was designed as the primary resource for instruction in science. Currently, science in elementary schools, where taught, is likely to be fragmented with an inherent lack of sequence or continuity.

Given the predominance of the subject/discipline-centered curriculum in the past and its inherent underlying philosophical assumptions (an epistemology of knowing by authority) and given attempts (well grounded in an epistemology of discovery) to broaden the process basis of the science disciplines during curricular revisions of the 1960s, science educators when contemplating directions for science education today must also address the challenge of adopting more problem-centered curricula (based on a reconstructionist epistemology of pragmatism).

The vast literature in science education in the 1980s contains hundreds, perhaps thousands, of articles that describe the solution to the crisis in science education as a science-technology-society approach--essentially adding a problem-centered emphasis to science in schools. Problem-centered designs exhibit a flexibility not readily apparent in subject-centered designs. The focus is generally on local and global contemporary social problems, but adjustments are made to accommodate the concerns and situations of learners. Content is taught on the basis of relevance and background to the problem. Sequence can be determined either on the basis of problem or issue classification or on the basis of needs and abilities of students. The focus is on problem-solving procedures for learning. Thus, proposed new science curricula continue to emphasize a process approach that is integrated with basic concepts. New science programs continue to draw heavily on disciplines subject matter and also stress application to social, environmental, and technological problems. Student concerns may serve as a starting point for consideration of more general local, regional, or global issues. Content from several subjects may be integrated to better understand issues. Information is acquired for a purpose--to

discover and internalize meanings which are then applied to resolve a functional problem of relevance to students and society. The intent is to develop citizens who are capable of critically analyzing and evaluating social and environmental conditions and are competent and motivated to participate in directing the evolution of society. Textbooks and materials that facilitate this approach are becoming much more readily available in the rapidly expanding science-technology-society and environmental education literature.

Relationship of Science Education to the Core Curriculum

The core curriculum is essentially a problem-solving design that originated around the turn of the century as a reaction against the fragmentation brought about by separate subjects. It intends to provide common learnings or general education needed by all individuals for effective functioning in society. Because the elementary curriculum consists almost entirely of basic common learnings, the core development has been directed primarily at the secondary level where the curriculum has traditionally been regarded as excessively specialized and fragmented.

According to Taba's (1962) classification, the core curriculum proposed for Saskatchewan appears to be a correlated core. Provision is made for integration of content. One variant of this approach retains basic subject content but selects and organizes this content with reference to broad themes, problems, or units. An example of a theme used to correlate concepts from social studies and science is conservation of natural resources. Social studies elements might include pioneers' use of the land and forests or social factors in strip mining coal. Science might introduce technology of soil conservation, chemistry of coal, or ecosystem change due to strip mining. Scope and sequence in a correlated core are governed by subject area content. As such, a correlated core is a variant of a subject-centered tradition that is attempting to avoid problems of fragmentation and relevance. Any further departure from traditional subject-centered curricula will likely be viewed as neglecting fundamentals and would not be acceptable to the public. However, the argument from leading science educators is strong--science-related social problems must be addressed in the schools (Bybee, 1985a, 1985b). The public is being asked to decide on crucial social-environmental problems with "expert" opinions supporting alternative value positions. For example, what proportion of national or provincial economic resources should be expended on environmental protection (e.g., high energy costs for strip mine reclamation)? The solution we arrive at will affect the way people live for generations. Other crucial social problems include poverty, world hunger, population control, conservation of natural resources and energy, inflation, racism, war, nuclear power, and medical ethics (Gaskell, 1982).

Social concerns become problems because individuals and social groups perceive them differently and advocate conflicting solutions. Because perceptions are largely governed by values and attitudes, these factors are important in problem

solving. The primary thrust of science-technology-society-environment education is to emphasize rigorous study of social problems and to develop the habit of critical thinking. Thus, students are prepared for effective adult participation in democratic decision making. Sequence is governed by psychological factors such as maturity, experience, prior learnings, interests, and difficulty (Hurd, 1984).

When considering the design of the science core within Saskatchewan's proposed core curriculum, several problems must be addressed. Decisions are required in the determination of whether to focus on general or specialized education, or both. If general education is to be emphasized, design will tend to be determined primarily by the disciplinary demand and factors such as cultural norms, human ideals, ethics and values, and lifestyles must be accounted for. These value issues are so deeply rooted and complex that a curriculum design can be articulated only after long and difficult inquiry into substantive foundational issues. Another concern of curriculum design is maintaining a relationship among aims, goals, and objectives (common essential learnings, core, and science core); subject matter; learning experiences; and evaluation. If we are serious about developing common essential learnings, then learning experiences must contain objectives and activities of much wider scope than currently exists. Evaluation mechanisms must be developed that reflect, in a manner acceptable to parents and teachers, the entire range of learning experiences.

A third problem of science curriculum design is that of scope and sequence. As learners develop, what elements should be reduced, eliminated, added, or expanded? Relationships among elements at given levels must also reflect consistency and continuity. Traditionally, content has been sequenced with little consideration given to process especially at secondary levels. One problem associated with scope and sequence is a breadth vs. depth dilemma. The broader the scope, the less possibility there exists for depth. In an attempt to resolve some scope and sequence problems, Goodlad (1963) suggested using organizing centers such as books, field trips, problems, events, or experiments to define the substance of learning at particular levels. His second organizer is the organizing element (concept, generalization, process, or theme, e.g., energy) on which organizing centers could be longitudinally clustered.

The problem of balance involves ensuring appropriate weight is given to each aspect of the design so that distortions are minimized. For example, should subjects be taught sequentially (subject-centered) or functionally (learner-centered) or both as in core problem-centered designs? The matter of balance is complex, involving integration of subject matter and learners. Discipline approaches may overemphasize content and neglect the breadth of objectives stated in the curriculum (Roberts, 1982). Core approaches tend to view learning in terms of process whereas subject-centered curricula view learning in terms of content. In summary, according to Stratemeyer, Forkner, McKim, and Passow (1957, pp. 110-111), consideration of the following seven fundamental curriculum design questions appears to be essential to sound curriculum planning:

1. How can balanced development be assured? What guarantees can there be that important areas of life in which students or teacher are insensitive to problems will not be neglected?

2. How can there be continuous growth from year to year without undesirable repetition or undesirable gaps in learning?

3. How can desirable depth of knowledge be assured? How is it possible to prevent learners from ending up with a smattering of superficial knowledge about many areas and little of the depth they need for genuine understanding?

4. How will the depth of command of special subject areas important to individual learners be assured? Where will the persons with specialized talents come from--the scientists, historians, linguists, artists, teachers, statesmen, philosophers of the future?

5. How can it be guaranteed that children and youth will become acquainted with the broad cultural resources which are part of our heritage and become skilled in drawing upon and using these resources in meeting life situations?

6. How can there be guarantees that choices of problems are not trivial and do not represent transitory interests rather than basic concerns?

7. How can there be genuine group problems? Will there not actually be many times when extrinsic motivation will be needed if group study is desired? Does the point of view not logically lead to work that is completely individualized?

Given these general statements related to curriculum theory as a foundation for program development, there remains the task of synthesizing the science education literature so that these general principles can be applied directly to specific science program development decisions. This follows the next section which focusses on Saskatchewan science curricula as related to the "core" proposal.

Science Curricula in Saskatchewan

Given a background which attempts to provide a foundational basis in curriculum theory for science program planning, the next logical stage in policy construction is to ground science curriculum design within the core curriculum established by Saskatchewan Education (see Taba, 1962, p. 439). The following sections will attempt to characterize science education curricula in Saskatchewan in order to provide information for policy development. Elementary school science education (K-6) will be discussed first, followed by intermediate level science curricula

(7-10) and the specialized science disciplines (11-12). Departure from the division system was necessary because Science 10 is basically a general science course that follows the Grade 7-9 format and because the new core curriculum dissolves the division system as a basis for curriculum organization.

Elementary Science (K-6)

Young children are naturally curious about the world around them. If science is begun early in school and taught effectively, it can provide a good foundation in subject matter, modes of inquiry, and attitudes. However, very little science, often none, is taught in Canada's elementary schools (Science Council of Canada, 1984). Given the data base of the science education study of the Science Council of Canada, what is concluded about Canadian schools is very likely true of Saskatchewan schools. Many children are not receiving adequate science education. This is so despite the fact that many recommendations for science education in the Science Council of Canada's report can already be found as stated aims or objectives in curriculum documents of ministeries or departments of education. Saskatchewan, similar to other provinces, lists essential concepts, processes, and attitudes with little comment on relative priority. Concepts are referenced by grade and division level.

In elementary school science curriculum documents, development of skills and attitudes are considered more important than concepts or subject matter. However, in Saskatchewan a wide gap exists between department intentions (intended curriculum) and classroom practice (taught curriculum). Few elementary schools have science taught during prescribed periods by confident teachers with the support of adequate facilities.

The curriculum guide, Science: A Curriculum Guide for Divisions I and II (Saskatchewan Education, 1971a), outlines four conceptual schemes (and subconcepts) for each of the six grades. Suggested activities provide detailed ideas for teaching concepts. Selected units are suggested from the ESS series, the SCIS curriculum, and the Experiences in Science series. However, teachers appear to have difficulty relating specific activities to broad concepts. Problems also exist because teachers do not feel that these curriculum guides provide enough structure or guidance to accommodate their lack of background in science.

Intermediate Science (7-10)

At the Division III level, science courses are more frequently taught by teachers with some science background. Whether these subjects are taught in K-12 rural schools, elementary schools, junior high schools, or secondary schools, some specialization of teacher duties seems to occur. A new curriculum guide, Science: A Curriculum Guide for Division III (Saskatchewan Education, 1979), was developed that intended a directed discovery approach; provided detailed basic

activities (Supplementary Activities Guide); and suggested topics, texts (a multi-text approach in theory), and references for life science (7), earth science (8), and physical science (9 and 10). Students in Grade 10 must also take a science course, and a curriculum guide similar to the Division III guide has been recently developed (Saskatchewan Education, 1980).

The intended curriculum in Saskatchewan appears to be progressive and innovative. The science program is built on four principles: an activity approach, combined use of a number of texts, the Saskatchewan example, and the human element in the science process. Sufficient curricular structure is provided for nonscience specialists, and sufficient flexibility is allowed for specialists. Teachers are encouraged to develop activities and special studies of local interest, vary instructional strategies, relate material to students' lives and to society, and use varied evaluation approaches. The program goals are comprehensive and contain essential components for the development of scientific literacy. They relate to environmental literacy, aesthetics, communication, problem solving in the broadest sense, values clarification, inquiry strategies, and science in society.

The taught curriculum appears in many instances to have been reduced to the lowest common denominator--a textbook science curriculum, with frequent complaints about the "chosen" text. The text determines the sequence and scope of activities, lectures, and demonstrations, and text-based laboratory periods characterize the course. Division III teacher surveys reveal a great deal of dissatisfaction with the grade 10 curriculum because of inadequate textbooks. Examinations tend to be content recall. Division III science in Saskatchewan represents a classic example of incongruency between intentions and transactions/outcomes.

Secondary Science (11 and 12)

Currently, Saskatchewan's Division IV science curricula are discipline-based courses in biology, chemistry, and physics. A few students elect optional geology (12) or agriculture (11 and 12), a course currently under revision. In their provincial review of science education in Canada, MacKeracher and Jantzi (1985) characterized the secondary science courses in Saskatchewan as follows: biology is text based, chemistry is content based, and physics is objective based. As mentioned in the section on curriculum foundations, Saskatchewan secondary curriculum committees "bought into" the National Science Foundation curriculum projects of the 1960s and continue to use various editions of the basic texts. There are exceptions. For example, Modern Biology, which was the precursor of BSCS biology in Saskatchewan, remains on the authorized textbook list and is used in many schools. Biology curriculum guides have not been updated since 1971 (Saskatchewan Education, 1971b), supplement excepted, whereas new chemistry and physics guides were developed in 1976. However, the original CHEM Study texts and new editions of PSSC physics texts guide the curricula in many schools (Saskatchewan Education, 1976a, 1976b).

Intended curricula in each of the secondary sciences, given their origin, emphasize a conceptual framework approach to the discipline. Initially these curriculum projects emphasized more innovative concepts, a laboratory approach, tests that developed high level applications of information, and extensive resources. Similar to the Division III curriculum guide, wide-ranging progressive goals were intended.

The Science Council of Canada (1984) reported serious discrepancies between intended and transacted or implemented curricula and between what teachers favored and what they claimed to attain. Secondary science in Saskatchewan schools is textbook-bound where the text governs scope and sequence. Content is taught primarily through lecture methods with some laboratory work and very little field work. Teachers complain about texts and time constraints as they focus on goals related to academic preparation for the next level of science education. They are largely satisfied with the role they are currently playing and favor a content-rich text as a key resource. Examinations are often multiple choice or short answer, stressing information recall. Students say they do not generally like secondary science and will not continue in a science career.

Summary

The intentions of Saskatchewan science curricula are not congruent with the transactions or outcomes in the classroom. In elementary schools (K-6), very little science is taught; some curriculum reorientation appears necessary. At the intermediate level (7-10), creative and progressive goals and objectives seem to be lost in the logic of a more narrowly focussed textbook curriculum. At the senior secondary level (10-12), even the innovative discipline-oriented, concept-based textbooks have largely been reduced to a content approach. If intended and taught curricula are incongruent, it remains to be determined what must be done if science teachers are to heed the warnings of science education's leading spokespeople and periodicals. The science education literature points overwhelmingly to a major crisis in science education and proposes some major changes in emphasis. The next section examines specific proposals for change in school science practice.

IMPLICATIONS FOR THE SCIENCE CURRICULUM FROM CURRENT RESEARCH

What can be learned from the current science education literature that might provide insight for policy and curriculum development? What promising major trends and directions are indicated for future science education? How meaningful and universal are the arguments for change? This section will analyze the current literature in science education and attempt to ascertain crucial factors that must be considered by future science curriculum committees.

Even a cursory examination of science education periodicals and yearbooks leaves the unmistakable and uncomfortable impression that something is seriously wrong with science education at all levels of schooling. Virtually every prestigious and influential commission, organization, or individual that expouses interest in school science has levelled severe criticisms at current practices. Even more interesting is the fact that, although the critics represent the entire spectrum of education's viewpoints, the vast majority of groups and individuals espouse similar solutions to the problem (see Bybee & Yager, 1982). Implications for policy formulation and curriculum development from the science education literature are reasonably consistent and clear. Science education in the schools must change by broadening its base to include a science in society (also known as science-technology-society or science-technology-society-environment) emphasis. The documentation that follows is intended to illustrate the nature and extent of the demand for renewal in science education within certain categories.

The Science Council of Canada's science education study (Orpwood & Souque, 1984) discussed a number of criticisms of science education. At issue was the fact that students do not come to appreciate the personal, social, or national relevance of science. Other criticisms included the Canadian public's ignorance of the effects of science and technology, elitist school science that miseducates students and fails to develop interest, poor scientific attitudes among students and some teachers, and an imbalance of aims of science teaching. For example, science taught only as a body of knowledge encourages intellectual dependence and fails to develop independent thinking and practical problem solving or citizens capable of participating in and understanding science-related social issues or political decision making. The science education study of the Science Council of Canada provided a factual basis that validated these claims. The study reported eight case studies that indicated significant variations between department or ministry of education science curriculum guidelines and classroom practice. The study's survey of teaching practices revealed that, in the absence of clear priorities for science education aimed at the department level, school boards and teachers choose the objectives to be emphasized in the classroom.

Where science is taught in early years and at middle years, teachers stress science skills and attitudes. At senior levels, the learning of science content is emphasized. Technological, social, and Canadian cultural contexts of science are not systematically covered in science courses, usually because of a stated lack of time or because teachers state that they lack the academic training required to teach with these emphases.

The Science Council of Canada's science textbook analysis revealed that most texts (and science education beyond sixth grade in Saskatchewan is essentially a textbook curriculum) stress only the learning of science content and skills or the structure of the discipline. Laboratory work is highly structured and there are few opportunities for class discussion. At the elementary level, most teachers are inadequately prepared to teach science, teach science only rarely in designated periods, and function without adequate equipment or facilities. At middle and senior levels, the learning of science content is considered to be all that time allows. Preparation for further study is the aim most in evidence (see also Roberts, 1983).

Most tests and examinations measure only how much scientific information a student has learned. Other objectives are not evaluated and thus have little importance to students. High achievers complain of the lack of challenge in science courses; many girls give up science subjects as soon as possible. Many other concerns and criticisms may be gleaned from examination of the detailed Science Council of Canada reports. However, the message is clear--these criticisms are cause for concern.

Deep concern for the state of science education is worldwide. Baez (1980), who examined science education from firsthand experience in many countries of the world, finds science education in universal need of improvement. The late 1970s and early 1980s have been characterized as a time of assessment in science education (Anderson, 1983b). A large number of conferences, research reports, science assessments, and status studies have confirmed internationally the general findings of the report of the Science Council of Canada. Many of these conclusions may be found in the goals and philosophy sections of that report. There is absolutely no doubt that serious problems exist in the field of science education. What does current thought and research in science education propose to remedy these problems?

Many organizations and individuals have attempted to respond to this question and the responses are largely consistent--broaden the base of current practice in science teaching to include a focus on the interaction of science, technology, environment, and society. There are many implications of this attempt to broaden the world view of science teachers and to broaden the epistemological base of science teaching. These implications must be clarified so that curriculum development can proceed from a more informed conceptual perspective.

Influential organizations such as UNESCO (1981), the Science Council of Canada (1984), the Association for Science Education in Great Britain (1981), the National Science Foundation (Nelkin, 1982), the National Science Teachers Association (Bybee, 1985a), and the Association for the Education of Teachers of Science (Abraham & Fox, 1979) have conducted conferences and published position statements, policy documents, or yearbooks that advocate, promote, or endorse a science in society concept of science teaching that is much broader than currently exists in schools. According to Hurd (1986) the central issue in the reform of science education is the gap between the demands of living in a scientifically and technologically driven society and the existing character of science in the classroom.

Many influential science educators in Canada and other countries have written of the necessity for infusing science teaching with a science in society emphasis (Aikenhead, 1980, 1985a; Anderson, 1983b; Baez, 1980; H.H. Birney, personal communication, October 5, 1985; Blosser, 1985; Brandwein, Cross, & Neivert, 1985; Bybee, 1985a,1985b; Champagne & Klopfer, 1982b; Fensham, 1983; Gallagher & Yager, 1980; Gaskell, 1982; Harlen, 1984; Harms, 1981; Hickman & Kahle, 1982; Hurd, 1983a, 1983b, 1984, 1985, 1986; Lucas, 1980, 1981; Mayer, 1979; McConnel, 1982; Olson & Russel, 1984; Orpwood, 1985; Penick, 1986; Peterson, Bowyer, Butts, & Bybee, 1984; Roberts, 1982; Roy, 1986; Searles, 1984; Stake & Easley, 1978; Thelen, 1983; Thier, 1985; Watson, 1983; Welch, 1985; Yager, 1983a, 1984, 1986; Ziman, 1980).

A science in society approach to science education may also be described as a science-technology-society approach or a science-technology-society-environment approach. These alternative descriptors are probably subsumers of a broadly defined science in society approach but when included, labels serve to call immediate attention to the desirability of technological and environmental as well as scientific literacy. Whatever the title, the growing consensus among science educators and others concerned with education in the sciences is that because of shifts in the culture and changes in the interrelationships between science, technology, society, and environment, a need exists for a new rationale for education in the sciences. A framework based on such a rationale would reflect the meaning of science in the social and environmental context and acknowledge the relationship of science as part of social policy and of technology as part of science policy.

The implications for science teaching are significant as illustrated by the following reform issues:

1. School science courses should be in accord with the image and ethos of modern science and technology. The classical description of science and its methods of inquiry found in the majority of science textbooks is characteristic of past decades. Considerations of technology as it influences research in

the sciences, modifies social processes, and changes the human condition should be an integral part of the science curriculum.

2. The present secondary school science curriculum is ill-suited for purposes of general education. National studies in Canada, Great Britain, and the United States are calling for a reassortment of what is known in the whole field of science and technology (and environment) to identify concepts that have personal and social relevance as well as scientific, technological, and environmental validity.

3. The goal most frequently named by national studies for the teaching of science is scientific and technological literacy. Literacy is conceived to be those intellectual skills and understandings essential for one to make responsible decisions or to take cognitive action in situations that require an understanding of science or technology, for example, the use of nuclear power, choice of lifestyle, management of the natural environment, replacement of workers with robots, control of human population growth, discovery of new energy sources, transplants of human organs, and attainment of optimal health and vigor. Scientific and technological literacy can be taught only in situations where science and technology interact with personal or social events. Literacy refers to a level of science understanding that makes it possible for a person to use what he or she has learned to think critically about relevant issues or to interpret natural events in the world.

   Traditionally, science teaching has only been concerned with matters of fact and how knowledge is discovered and validated. There is a vast difference between the acquisition of information and having the capacity to use it. A major criticism of science education by students and their parents is that too much of what they learn remains forever inert, never transferrable or retrievable. National studies point out that, in spite of all the science facts they learn, students exist in an information vacuum.

4. Using scientific and technological information with insight and wisdom informs decisions that are based in part on preferences, aspirations, emotions, ethical judgments, value considerations, and sometimes a moral choice. Science and technology have a value dimension any time they induce conflicts in thinking, modify culture, or change society, and this is most of the time. The teaching objective is to develop student awareness that value and ethical judgments should be well grounded in scientific and technological knowledge.

   Value positions and ethical judgments in science represent a choice of action based upon an evaluation and interpretation of valid information. For example, when students examine the increasing demand for more energy worldwide, the depletion of nonrenewable energy resources, and the possibilities of nuclear power, they are evaluating realities, probabilities, and

risks. What is sought in teaching is a reasoned judgment for action. It is not expected that all students will choose the same action or that a collaborative decision will be the same as an individual might make.

This instructional approach is not the same as teaching a set of values. The significance of presenting ethic-laden issues in science courses is illustrated in a comment made by Stephen Toulman, a philosopher of science at the University of Chicago: "... it is no longer possible to draw so clear a line between the intellectual demands of good science and the ethical demands of good life."

5. Little is to be gained from making decisions or value judgments if the information base is unreliable. In decision making, due weight must be given to evidence and data. To improve the quality of their decisions, students must be able to distinguish:

   - evidence from propaganda
   - probabilities from certainties
   - rational beliefs from superstitions
   - sense from nonsense
   - science from myth and quackery
   - data from assertion and fantasy
   - fact from fiction and folklore
   - reality from illusion
   - theory from dogma
   - credible from incredible
   - observation from inference
   - knowledge from opinion and impressions
   - truth from falsity.

6. Anticipated changes in society and the workplace, the exponential growth of scientific knowledge, and ever-new innovations in technology make lifelong learning imperative. We can no longer accept the idea that an education in the sciences terminates with formal schooling. Providing students with the conceptual base and the learning skills essential for continuing self-directed learning throughout life becomes an important objective of science teaching. Students will need to be aware of reliable sources of knowledge and to recognize expertise. They must also acquire the skills essential to process information such as the ability to analyze, synthesize, codify, evaluate, and reason logically. The potential of computers to supply large amounts of in-

formation upon demand should be recognized as well as the fact that they do not think or make wise decisions.

7. A portion of the science curriculum should be organized in terms of on-going science-technology-social issues such as population growth, food resources, space exploration, energy conversion, lifestyles and health, the chemical basis of human behavior, communication systems, technology and the economy that are problems that students must deal with throughout their lifetime. These are the issues in which the student is a part of the problem as well as a participant in the solution. This approach makes for a curriculum oriented toward the future where the student will live, work, and have a responsibility for improving the quality of life.

8. It is not a responsibility of the secondary school to offer science courses designed to provide the first step in the professional training of a scientist or researcher. But is it desirable, where qualified teachers and laboratory resources exist, to offer discipline-based courses for students who wish to test their interest and ability to pursue careers in science and technical fields? These courses do not substitute for those designed for general education, they are in addition.

   Inherent in the proposed general education courses in science are many of the core competencies students will need to enter and advance in the changing workplace. Employers have identified these primary capabilities as:

   - ability to reason and solve problems logically and quantitatively
   - knowledge of sources of information and how to process it
   - maintaining a healthful lifestyle
   - making wise decisions independently as well as in collaboration with others
   - appreciation that change is inevitable in all aspects of life and work
   - knowledge and willingness to learn new things
   - understanding the interaction of science, technology, and the economy (Hurd, 1985, p. 87-90).

The reform of science education will not be achieved by "dusting off" and restating traditional goals or "tidying up" the curriculum with a few up-to-date topics in science. According to Hurd (1985), a synthesis of recommendations for reform requires science teachers to aim at developing students capable of and motivated to actively participate in a science and technology-oriented society. To accomplish this goal teachers must rethink their beliefs on what is worth knowing about modern science and technology to enable students to respond with wisdom to the demands of social change. The essential skills to be developed in science teaching

are those necessary for accessing, processing, and using information in the contexts of thinking critically, making decisions, and forming ethical judgments. These are also the skills needed for sustaining independent and lifelong learning. These goals and curriculum theories should form the rationale for a common curriculum core in science education. The science teacher must assume broader responsibility than simply passing along information and developing laboratory skills. This is the essence of the strategic vision that is required for strategic curriculum planning.

A shift towards a science curriculum that is more personally and socially relevant, it is argued, would be more appropriate for students who will be future consumers of science rather than future producers (Aikenhead, 1980). Such a shift in emphasis might also help to increase the participation rate of women in upper level science courses (Kelly, 1981).

The Science Council of Canada (1984), based on the findings of the first national study of science education in Canada's history, identified eight major recommendations for science education. Six of those objectives contain direct written references to the science-technology-society emphasis required for the renewal of science education in Canada. The implications are clear.

The depiction of a philosophy for science education for Saskatchewan which follows attempts to present a balanced concept of curricular emphases in science education (after Roberts, 1982). But it should be remembered that balance among goals is not the same as balance in teaching toward these goals--a situation which currently does not exist in science classes in Saskatchewan.

The remainder of this paper is devoted to an exploration of current thought and research in science education within headings prescribed as guidelines that should focus on implications for curriculum development by Saskatchewan Education. The headings used to guide the literature analysis include the following as related to science education: philosophy, goals, instructional strategies, evaluation, controversial issues, integration of science with other school subjects, relationship of science education with environmental education, postsecondary articulation, individual and group needs, and the relationship of goals of science to goals of education as represented by the common essential learnings in Saskatchewan's proposed core curriculum. Material under each of these headings is intended to provide a basis for curriculum development in science education and this focus delimited the literature search.

Philosophy

Nature of Science

Science is a creative process which attempts to discover and understand, thereby generating knowledge. It is characterized by certain values and attitudes that have developed by the example of thousands of scientists who have long sought explanations for observed phenomena. Today, scientific inquiry uses established procedures of observation and investigation to: formulate hypotheses about relationships among variables, gather data, analyze results, and draw conclusions. At times discoveries are new; at other times they merely alter current concepts, laws, or theories. As scientific knowledge grows, scientists are always prepared to alter the point of view they use to order their experiences. Science is a process that continually questions all things, thus opening itself to continual scrutiny and modification.

Science is often viewed as both a product and a process. Some individuals choose, consciously or unconsciously, to emphasize or focus on only one aspect of science. Students should, however, be exposed to a balanced view of science. There are sound reasons for this. The learning of key concepts and generalizations identified by scientists is imperative in science education because it increases intellectual power. Concepts as categorizations aid in understanding by making learning more efficient and by facilitating more complex attempts to understand relationships or regularities among concepts. Basic concepts and generalizations can provide a framework for thinking about how the world works.

Process involves use of science methods such as observation, classification, and experimentation in combination with human thought to attempt to solve problems. For children, it is possible that the process used for learning is more important than the final result of the activity. These processes are also called thought operations and reflect their discreteness as components in the complex overarching process of thinking.

Active involvement in problem-solving activity can foster understandings related to the nature of science and scientific knowledge which may be characterized as tentative, public, replicable, probabilistic, human-related, historic, unique, holistic, and empirical.

Science programs should permit the child to encounter the world on a level where understanding can develop. Without knowledge, children cannot understand themselves or their world; without a way of knowing, they cannot experience the excitement of the search. If children are to learn science, they must experience all its facets.

Teacher Education

What is taught in school science classrooms and how it is taught is greatly influenced by teachers' ideas about the nature of science, education, the curriculum, society, and the learner. Regardless of their understanding of education, the curriculum, and society, it is distressing that many science teachers--experienced and inexperienced--have an unclear picture of the nature of science (Carey and Stauss, 1968; 1970). They also do not understand the interactions among science, technology, society, and environment, and as a result they are unable to adequately instruct their students in the area of science-related societal issues. Such a deficiency is understandable because their experiences have been limited in these areas. If teachers are unable or unwilling to help students develop an understanding of science-technology-society-environment relationships, attempts to promote scientific-technological-environmental literacy are seriously restricted (Collette & Chiappetta, 1984).

Science-Technology-Society-Environment

Science has always had an impact on society. In recent decades, the rate of scientific knowledge production has increased dramatically. New scientific knowledge has resulted in technological advances that may improve the quality of life or threaten it. The demand for science to solve many of the world's problems has fueled the development of technologies that can advance medical science, space science, organic chemistry, and engineering science. At the same time, advances in electronic media have vastly increased the capacity to bring news of scientific discoveries and problems to world attention. When technology fills the marketplace with inventions, gadgets, and sophisticated hardware, consumers face bewildering decisions about what to purchase and how to intelligently use these innovations. When scientific investigation foresees difficulties in the availability of future energy sources, pollution, or environmental degradation, the impact of these findings ripples through the very fabric of society affecting economics, politics, jobs, lifestyles, and the quality of living for all citizens. When there is a rapid growth of technology-dependent industry, there are increased demands for a technologically literate labor force. When scientific research suggests new and daring possibilities in areas of nuclear energy, genetic engineering, pesticide development, and artificial life support, people must deal with moral and ethical value questions that have never been part of society's concerns.

In addition to these changes, world population growth coupled with increasing use of technology in developing and developed countries has caused accelerated depletion of natural resources and an unprecedented scale of global environmental destruction. It is clearly necessary to develop environmental literacy so that the human impact on global ecosystems is understood. Increasing demands on earth's limited resources have resulted in growing dependence upon synthetics. This dependence has, in turn, given rise to disposal problems for toxic wastes, radioactive

wastes, and persistent pesticide residues. There are no new large uncharted land surfaces. The quality of human life in many areas is threatened. Everything is connected to everything else. We must deal with our problems ourselves. The most serious problems facing society are unprecedented in scope and magnitude. Problems require interdisciplinary solutions of great complexity. Scientific decisions have economic and political implications.

The quality of life on this planet and the welfare of the world's population are closely linked to science-technology-environment and the politics of society. Future decisions and problems demand that people in society recognize the interdependence between scientific and technological developments and the quality of society and environment. Teachers can play an important role in fostering this understanding by developing an understanding of science and technology within the context of environmental quality and societal progress.

A comprehensive approach to science teaching requires that learners receive the essential readiness skills to become scientifically, technologically, and environmentally literate. This approach also requires that science teaching provide students with a foundation for making sound decisions and for developing a feeling of control over their lives as they learn how to participate in societal decision making.

Science and the Learner

Children are naturally curious about their environment. Young children observe and openly seek to understand what they see. Some teachers get their greatest pleasure from helping young children pursue their enthusiastic involvement with nature. In no other activity are children quite so open and questioning, quite so willing to express their feelings and thoughts. Science, teachers find, is the near-perfect vehicle through which to help children develop their thinking skills. This, then, is the pleasant task of the elementary science teacher--helping children acquire the skills and knowledge necessary to understand the world around them (Abruscato, 1982; Esler & Esler, 1984).

The beginnning of science is wondering. The most important thing that a science teacher can do for children, adolescents, or adults is to nurture or rekindle the innate sense of wonder or curiosity that drives humans to seek explanations for observed phenomena. Curiosity is the same across barriers of time, race, and geography (Carson, 1956). Classrooms are often viewed as places for sitting and listening or reading and working on assignments. Many science educators believe that there must be a better balance in school programs that permits children more time to be actively involved with things in their environment (Esler & Esler, 1984).

As adolescents and adults, curiosity and wonder about the environment may be less intense than it was in childhood, yet curiosity and wonder are the "stuff" of

survival. Why?, What?, When?, and How?--responses to these questions help children learn to make sense of their world. Teachers can help students develop practical skills to foster their ability to explore and make sense of their natural and human environments (Abruscato, 1982). Those who are bored with life have somehow lost their curiosity. They live out their lives dully, ever-confident that curiosity killed the cat, when in reality ignorance killed the cat. Teachers are constantly surrounded by students who have not lost their curiosity. An indicator of good science teaching is teachers whose curiosity constantly motivates themselves and their students to ask questions and actively search for answers as they together seek to develop an understanding of the world. The way to nourish curiosity is simply to be curious with children. The challenge is really not so difficult because children bring so much energy and natural curiosity to the quest (Abruscato, 1982; Jacobson & Bergman, 1980).

Parents and teachers have special opportunities and responsibilities to help children explore and find out. Encouraging and supporting children as they explore their environment, answering questions, finding time to explain or access materials, planning special experiences, and stimulating inquiry are ways that parents can help children learn. Teachers have special responsibilities for helping children in their intellectual development. They can help children gain experience with concrete materials that gives meaning to words and numbers. They can plan science learning experiences that appear to be necessary prerequisites to children's acquisition of the ability to engage in formal thought. They can help students 'earn how to learn. Learning how to go about solving problems empirically--as one way of knowing--can enrich the lives of students by providing decision-making skills that will serve them well as adult citizens who must become involved in science and technology-related societal and environmental issues (Jacobson & Bergman, 1980).

Educators have the challenge of developing or selecting curricula that stimulate curiosity and exploration. In early grades, the science curriculum must provide concrete experiences in class and in the environment in order to develop awareness and understanding of the students themselves and the environment--urban, rural, or natural. Experiences must be direct and hands-on so that students can interact and personally relate. The imperative is clear--approach science as student activity, activity that stimulates inquiry.

In later grades, where enthusiasm for discovery is moderated by personal change and maturation and development of self-awareness and self-esteem, students are becoming more mature intellectually and are becoming more able to deal with abstract concepts and formal ideas. Here science should focus on providing these students with a learning environment that is challenging and stimulating. Curriculum planners must provide materials that stimulate high level thinking, problem solving, and decision making. Development of these skills allows students to sharpen their senses and learn to access and evaluate information. This empowers them to participate in solving science-related societal issues. Research

indicates that students must identify personally with their learning experiences in order to improve their sense of identity and self-esteem. Accordingly, the personal competence developed becomes intrinsically rewarding and self-perpetuating.

Goals of Science Education

Every science education periodical contains articles and many more general curriculum-oriented journals describe a crisis in science education (e.g., Hurd, 1983a; Opel, 1982; Press, 1982; Yager, 1984). The basis for criticism appears to be that students are completing high school scientifically, technologically, and environmentally illiterate. They lack the essential knowledge and intellectual skills to be responsible voting citizens (National Commission on Excellence in Education, 1983). These are serious charges and cannot be dismissed as simply alarmist political rhetoric that reflects social and economic unrest (Hurd, 1986).

The curriculum reform era of the early 1960s resulted in many new science curricula. Earlier textbooks had consisted of a mass of disconnected facts and generalizations presented almost entirely as description that seemed to require rote memorization (Kyle, Shymansky, & Alport, 1982). The new curricula embodied both scientific processes and the nature of scientific inquiry (Peterson et al., 1984). Programs emphasized learning by doing while focussing on concepts in science according to the structure of the disciplines. Laboratory skills and higher cognitive activities were emphasized (Hofstein & Yager, 1982).

By the mid-1970s, however, after twenty years of experience with these "new" curricula, problems were beginning to surface. Status studies designed to assess the impact of the programs and identify new directions led to further calls for revision. The most striking finding of Project Synthesis, which was designed to synthesize four comprehensive status study data bases in science education (Helgeson et al., 1977; National Assessment of Educational Progress, 1978; Stake & Easley, 1978; Weiss, 1978), was that goals included in only one of the four goal categories, academic preparation, were almost the exclusive focus of science teaching in schools (Harms, 1981). Goals pertaining to personal needs, societal issues, and career education were largely ignored in classrooms and in textbooks. The reasons for this could be found by examining common school practices, the influence of textbooks, and societal pressures (Koballa, 1984).

In Canada, the results of the comprehensive study of science education by the Science Council of Canada (1984) employed a different methodology but produced similar results. Yager (1983b) described several conditions that illustrate the current crisis as follows:

1. Nearly all science teachers (90%) emphasize goals for school science that are directed only towards preparing students for the next academic level (further formal study of science).

2. Over 90% of all science teachers use a textbook 95% of the time; hence the textbook becomes the course outline, the framework, and the parameters for students' experience, testing, and world view of science.

3. There is virtually no evidence of science being learned by direct experience.

4. Nearly all science teachers "present" science via lectures and/or question and answer techniques based upon the information that exists in the chosen textbooks.

5. Over 90% of the science teachers view their goals for teaching in connection with specific content; further, these goals are static (i.e., seldom changing) givens.

These findings are similar to those of Goodlad (1983) who concluded that students in his sample did not appear to develop any of the abilities commonly listed under "intellectual development" such as the ability to think rationally, the ability to use and evaluate knowledge, intellectual curiosity, creativity, or the desire and ability to pursue further knowledge. Only rarely did instruction go beyond students' mere possession of information to the level of understanding implications and applications of that information.

Teachers determine which of the goals of science education are pursued in their classrooms. They make the most important decisions about course content, instructional methods, and text adoptions (Olson & Russell, 1984; Stake & Easley, 1978; Weiss, 1978). Teachers still have considerable autonomy. For example, preparation of students for exams and later science courses appears to be the primary goal of most science teachers in spite of the fact that these practices conflict with stated curriculum goals of science education and with practices encouraged by parents, school administrators, and science educators (Anderson, 1983a; Hurd, 1983b; Mayer, 1979). Little regard is given to preparing students to use science in the personal, societal, and environmental decision areas (Stallings, 1982; Yager, Bybee, Gallagher, & Renner, 1982). Such practices may be the reason why a majority of students believe the things they learn in science classes are dull, are no fun, and have little relevance to the real world (Yager & Penick, 1984).

A major gap also exists between teachers' stated expectations for their students and their teaching practices. According to Harms and Yager (1981), teachers at all grade levels stated that they wanted students "to be able to compare and contrast phenomena, explore the interrelationships among living things, interpret environmental changes, make inferences from data, formulate hypotheses, observe and classify, develop habits of inquiry, and so on." However, classroom observa-

tions led to the conclusion that teachers were not able to square their performance with their theory (Goodlad, 1983). Other researchers support these conclusions and state also that classroom practices reflect neither an emphasis on inquiry and problem solving nor a concern for technological and societal issues. Teachers do not even view these practices as important despite their presence in the goal statements of curriculum guides (Harms, 1981; Stallings, 1982; Yager & Penick, 1984). Researchers observe that large amounts of nonlecture time are spent on seatwork and reading/question assignments despite research reports to the contrary (Olson & Russell, 1984; Stake & Easley, 1978; Weiss, 1978).

The almost total reliance on textbooks by science teachers has prompted several analyses of texts. Results indicate that those texts most frequently used in all science disciplines at all levels are largely devoid of the characteristics representative of any goals other than academic preparation (Hurd, 1983b; Pratt, 1981; Science Council of Canada, 1984; Stallings, 1982). However, "new generation" elementary texts emphasized the personal, societal, and career awareness goals better than elementary textbooks currently in wide use (Pratt, 1981). The scarcity of information and activities found in science textbooks at all levels relevant to these goals is evidence of the low priority that is given to learning experiences that will help prepare students for the problems they will face in the future (Koballa, 1984).

In summary, school practices in science education reflect goals that were established prior to or during the late 1950s. These goals were justified in terms of the social conditions of the time. Since the 1960s, major cultural transformations have occurred in culture and society. Science and technology increasingly penetrate social processes and human affairs. Teachers should recognize that the goals for science education have changed because society's needs and goals have changed. Society faces human and environmental problems unprecedented in scope and magnitude. Scientific advances bring problems as well as benefits. Decisions concerning societal welfare and personal competence often involve scientific and technological understandings. People are being forced to clarify their own values on many controversial issues such as in-vitro fertilization, abortion, increased longevity, nuclear power, and environmental ineptitude. The number and importance of such issues can only increase as scientific and technological advances increasingly penetrate our lives. As a result of these changes, society is now imposing pressures and forcing new directions for science teaching.

At present, many attempts are being made to define the goals of science teaching in terms broader than a consideration of science as a body of content or a set of processes central to science as a research discipline. There appears to be a need for more practical goals that stress care of personal, social, and environmental needs for today and the future. These goals stress the knowledge, skills, technology, values, and ethics needed to live in a science and technology-based society. New teaching approaches are emerging that organize science courses in terms of social problems, emphasizing humanistic, technological, and ethical dimensions

of science. The social dimension permits students to examine the activities with which they will be involved in the real world. This means that individuals must be scientifically literate to make judgments, resolve problems, and place value on the importance of science in today's society.

Scientifically literate individuals are those who understand how science, technology, society, and environment influence one another and are able to use their knowledge in decision making. A substantial base of facts, concepts, generalizations, and process skills can facilitate information access, analysis, and logical and creative thinking.

Although there is not absolute agreement on the form or content of goal statements for science education, based on an examination of goal statements generated by large science assessment studies in Canada (Science Council of Canada, 1984), Great Britain, (Association for Science Education, 1981) and the United States (Harms, 1981), there is clear evidence of a growing consensus about the following attributes that characterize a scientifically literate person. According to Collette and Chiapetta (1984, pp. 358-359), the scientifically literate person:

1. uses science concepts, process skills, and values in making responsible everyday decisions

2. understands how society influences science and technology as well as how science and technology influence society

3. understands that society controls science and technology through the allocation of resources

4. recognizes the limitations as well as the usefulness of science and technology in advancing human welfare

5. knows the major concepts, hypotheses, and theories of science and is able to use them

6. appreciates science and technology for the intellectual stimulus they provide

7. understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories

8. distinguishes between scientific evidence and personal opinion

9. recognizes the origin of science and understands that scientific knowledge is tentative and subject to change as evidence accumulates

10. understands the applications of technology and the decisions entailed in the use of technology

11. has sufficient knowledge and experience to appreciate the worthiness of research and technological development

12. has a richer and more exciting view of the world as the result of science education

13. knows reliable sources of scientific and technological information and uses these sources in the process of decision making.

For a more detailed list of the attributes of scientific literacy see Simpson and Anderson (1981) or Showalter (1974). These are reprinted as Appendix 1.

The Science Council of Canada (1984) identified eight major initiatives that are urgently required for the renewal of science education. These recommendations coincide with dimension categories discussed under scientific literacy above. They also include the following: guaranteeing science education for all in every elementary school identical to the recommendations in Great Britain (Association for Science Education, 1981) and the United States (National Science Teachers Association, 1982), increasing the participation of young women in science education, and setting science education in a Canadian context.

An interesting comparison of current Canadian provincial goal statements for science education can be found in a document produced for the Canadian component of the second international science study (Connelly et al., 1985). According to these researchers, lack of a national education body coupled with a strong provincial mandate for education greatly inhibits attempts to identify national educational goals. However, in spite of the quantity and variety of provincial documents, there was a high degree of similarity in the general outcomes anticipated as a consequence of practical applications, prudent consumption, and the development and implementation of science curricula. Although only Alberta and Newfoundland had written general science goal statements, others were inferred from curriculum documents (see Orpwood & Souque, 1984, pp. 62-64 or Connelly et al., 1985, p. 139; see also Appendix 2). Given the similarity in goal statements, the review by Haggerty and Hobbs (1981) of science curricula at elementary and secondary levels provides an excellent description of implementation differences across curriculum levels. Connelly et al. (1985) conclude that the actual content taught in the provinces and territories tends to vary more extensively than the general aims of science education. The goals and aims do not appear to be the problem. Teacher implementation is another matter.

Several other documents provide useful examples of variety by which goal statements are presented within science curriculum documents, whether elementary, middle, or secondary (see California State Board of Education, 1978, 1984; Con-

necticut State Board of Education, 1981; Maryland State Department of Education, 1984; Pennsylvania State Department of Education, 1984). In addition, a useful comparison of science education goals of the 1960s with those advocated for the 1980s and beyond has been summarized by Hofstein and Yager (1982) and is reproduced as Appendix 3.

There is strong pressure from the science education community to make immediate changes in school science. Many authors advocate the broadening of science education to include a science-technology-society approach (see, for example, Aikenhead, 1985a; Association for Science Education, 1981; Bybee, Peterson, Bowyer, & Butts, 1984; Gaskell, 1982; Harms & Yager, 1981; Hurd, 1986; McConnell, 1982; National Science Teachers Association, 1983a; Orpwood & Souque, 1984; Penick & Kyle, 1982; Science Council of Canada, 1984; Searles, 1984; Thier, 1985; Watson, 1983).

A rather small number of authors oppose the science-technology-society approach as not representing true science (Good, Herron, Lawson, & Renner, 1985), whereas Roberts (1982) argues for balance among several curricular emphases when setting goals in science education. This debate merits further discussion which is beyond the scope of this paper.

A significant number of groups and individuals stress the importance of environmental literacy (Fensham & May, 1978; Hungerford, Peyton, & Wilke, 1980; Lucas, 1980; McInnis & Albrecht, 1975; Stapp & Cox, 1982; Tanner, 1974; UNESCO-UNEP, 1976; Volk, 1984).

Other authors stress that, within a science-technology-society-environment framework, goals and objectives of science teaching must emphasize to a much greater degree the following:

1. science process skills and general inquiry processes (Welch et al., 1981)

2. problem solving, not in the narrow discipline-bound sense, but involving the use of science knowledge in making decisions in a real world context (Anderson, 1983a; Yager, 1982)

3. values, morals, and ethics as part of decision making involving science related social-environmental issues (Aikenhead, 1986; Brunkhorst, 1985; Mendelsohn, 1976; Thelen, 1983; Ziman, 1980)

4. career awareness (Harms, 1981).

In essence, proponents of change in science education argue that a new curriculum should be a mixture of goals that demonstrate that scientific knowledge is made concrete when it helps solve social problems, results in increased personal competence and heightened self-concept, and provides richer human existence. A syn-

thesis of recent research and current thought on science education provides clear evidence for inclusion of specific components in the curriculum. In summary, the contribution that science can make to the education of young people can be described in terms of the following goal statements. Science should involve:

1. acquisition of knowledge and understanding of a range of scientific concepts, generalizations, principles, and laws through systematic study and experience with science

2. acquisition of a range of cognitive and psychomotor skills and processes as a result of direct involvement in science activities in laboratory and field

3. utilization of science knowledge and processes in pursuit of further knowledge and deeper understanding

4. development of ability to function autonomously, to investigate and solve science and science-related social and environmental problems, and to communicate that experience to others

5. attainment of a perspective or way of looking at the world together with some understanding of how it complements and contrasts with other perspectives or ways of organizing knowledge and inquiry

6. attainment of a basic understanding of the nature of advanced technological societies; the interaction between science and society; and the relationships between science, technology, culture, society and environment

7. the realization that science as a way of knowing has value in the development of one's personal and social identity.

Within this goal framework, more specific aims and objectives of courses aimed at young people who are at different stages of intellectual development must be determined. The total curricular experience of all young people should provide adequate opportunities to explore science in all its contexts. This is essential if science is to contribute to student development by inclusion in a core curriculum. The needs of individuals will demand different emphases at different stages of the educational process. Thus, science must be viewed in a broader context than the traditional disciplinary slot currently given science in schools.

Instructional Strategies

The studies of the Science Council of Canada, the status studies of the National Science Foundation, and the case studies of the National Science Teachers As-

sociation have attempted to characterize science teaching in schools. Science instruction as currently practiced is described as predominantly lecture and recitation of textbook content where students rarely engage in activities for which answers are not provided by text or teacher. The goals of instruction and examinations emphasize knowledge recall. In fact, science teaching practices have not changed since the 1950s (DeRose, Lockard, & Paldy, 1979; Harms & Yager, 1981; Olson & Russell, 1984; Stake & Easley, 1978).

Wise and Okey (1983), in a meta-analysis of effects of various science teaching strategies, reflect the net result of Canadian and American case studies in their description of the typical science classroom. In such classrooms, students are not aware of instructional objectives, have few opportunities to manipulate materials, and are tested regularly on textbook information for purposes of reporting progress. The teacher generally follows the book, lectures, poses fact-oriented questions, and does little planning. As a result, students do not generally like science or science classes and state that they would not take another science class or choose a career in a science-related field (Yager & Penick, 1984).

Many science educators agree that specific changes in the science practices at elementary, middle, and high school levels must occur if goals that are included in the new consensus on science education are to be realized (Harms, 1981). Although science education is considered to be relatively young as a research-based discipline, Blosser (1986) indicates that recent research results, particularly meta-analyses, are pointing to instructional techniques which help students learn more effectively and are providing clear directions for constructing models of effective teaching. For example, Boulanger's (1981) meta-analysis of science education research 1963-78 indicated that of all instructional clusters, preinstructional strategies such as behavioral objectives, advanced organizers, or set induction produced the most significant gains in improving student conceptual learning, especially when associated with greater realism or concreteness of support materials. Thus, those teachers who use manipulative activities or hands-on experiences in appropriate instructional situations will be more effective in producing cognitive achievement than those who lecture, demonstrate, or have students read about topics. Achievement was also increased by the following: effective use of wait-time; use of focussing techniques; teacher tailoring or alteration of existing materials or personalizing some aspect of the instructional situation; effective questioning techniques such as varying the levels of questions or the positions of questions to involve the students and focus attention; use of formative tests to provide immediate or explanatory feedback for diagnosis or remediation; testing for mastery; inquiry/discovery techniques that were student centered and related to direct as opposed to indirect instructional strategies (Wise & Okey, 1983). These research results are fairly consistent with other recent research reviews in science education (Holliday, Helgeson, Blosser, & McGuire, 1985; Olstad & Haury, 1984; Peterson & Carlson, 1979; Sipe & Farmer, 1982). They are also consistent with the results of more general research on instruction (see Peterson & Walberg, 1979).

According to the results of four meta-analysis studies, science teachers must attend to the positive effects of inquiry teaching. In both elementary and secondary science, curriculum materials developed with an inquiry philosophy were found to be more effective in enhancing student performance (Anderson, 1983a; Lott, 1983).

Meta-analysis research on systems of instruction (general plans of instruction involving many aspects of an entire science program) indicates that personalized systems of learning and mastery learning--departures from conventional instruction--resulted in significant improvements on all learning outcomes (cognitive, affective, scientific methods, and critical thinking) compared with conventional instruction or individualized, media-based, audio-tutorial, computer-linked, or programmed instructional learning systems (Willett, Yamashita, & Anderson, 1983). In personalized instruction, learning is self-paced and modular, with little emphasis on lecture. A detailed study guide is included and a rich array of print materials is employed. Testing is frequent and feedback immediate as in mastery learning. Mastery learning, in combination with other techniques, appears to be a powerful instructional system and deserves attention by teachers who are looking for alternatives to conventional practices (see Bloom, 1971; Dillashaw & Okey, 1983; Dunkleberger & Heikkinen, 1983; Yeany & Miller, 1983).

At present, research on instructional strategies and systems can only provide hints concerning more effective teaching recommendations. Given the state of the art of research on teaching and on science teaching, incidents of effective practice must also be examined in order to find guidelines for improvement. Only recently has research on instruction, largely as a result of highly synthetical meta-analysis, been able to provide concrete suggestions about what is effective. For example, objectives should be communicated directly to students and related to performance criteria. Set induction, advance organizers, hands-on activities, focussed attention, effective questioning, inquiry, wait-time, formative testing with explanatory feedback, and considerable careful teacher planning and teacher and student personalization of curriculum materials appear to be more effective in terms of student learning than conventional lecture-dominated, textbook-sequenced science classes. From the study of characteristics common to exemplary programs and from case studies, we know much more about what constitutes an effective science classroom. The picture is becoming clearer and it is in vivid contrast to traditional classrooms (Bonnstetter, Penick, & Yager, 1984; Brown & Butts, 1983; Harms & Yager, 1981; McLean, Crocker, & Winney, 1984; Mechling & Oliver, 1983; National Science Teachers Association, 1983b; Olson & Russell, 1984; Penick & Meinhard-Pellens, 1984; Penick & Yager, 1983; Stake & Easley, 1978).

Certain observable characteristics are common to exemplary programs. Teachers are the most significant factor in effective classrooms. They are dynamic, thoughtful, young at heart, and eager to learn with their students, and they are professionals who want to teach science. Teachers in exemplary programs are

enthusiastic; take ownership of their programs which emphasize hands-on science, inquiry strategies, and student decision making; provide stimulating learning environments which frequently focus on societal issues and experiences outside classrooms; read professional journals, attend workshops and conferences, take college courses, and make presentations at professional meetings; and are actively involved in curriculum development and in staff development activities. Exemplary programs do not simply rely on lecture-textbook routines. Students actively do science; administrators are involved and supportive in terms of release time, inservice, and resources; the community is involved and supportive as are university faculty members and other community leaders. Curricula are often local adaptations of national curricula that integrate a balance of science processes and content and are directed at the majority of students, not just the college bound (Penick, 1983a, 1983b; Penick & Bonnstetter, 1984; Penick & Johnson, 1983; Penick & Lunetta, 1984).

Other researchers have added to the characterization of exemplary science programs. Jackson (1983) states that for more than twenty-five years, science educators have focussed on a type of science that, at secondary school levels, is appropriate for only 3% of the students. We have failed to provide science for all students that brings relevance to daily living and to current social issues (Association for Science Education, 1981; Miller, 1983; Science Council of Canada, 1984). We require a well-articulated science curriculum that balances content and process; provides problem-solving opportunities; enhances thinking; goes beyond the mere possession of information to applications; incorporates technological, societal, and environmental issues; and maintains a K-12 continuum which is well coordinated (Kyle, 1984).

Rowe (1983) discusses a framework for decision makers that attempts to capture the concern for personal and societal relevance by focussing on questions concerning problems and issues that adolescents may ask in determining personal meaningfulness. The questions are considered as four interdependent parts of a meaningful science program and include the following: ways of knowing (i.e., What do I know? Why do I believe it? What is the evidence?); actions/applications (i.e., What are the options? How do I take action?); consequences (i.e., What would happen?); and values (i.e., Who cares?). In order to use science to resolve personal and societal problems, students must understand the problems and how science is related to them. Students must have a chance to learn appropriate methods of problem solving. Curricula can be organized to meet these needs by injecting references to societal and environmental issues into each discipline or by using local, regional, or global social or environmental themes as organizers. This new curricular focus would emphasize the usefulness of scientific knowledge in examining real-world problems and would provide opportunities for active participation in decision making (Anderson, 1981; Harms, 1981; Hofstein & Yager 1982; Hurd, 1981).

Basic science knowledge and process should be a theme of science programs at all levels (Anderson, 1981; Yager, Aldridge, & Penick, 1983). However, science outcomes must also reflect personal, societal, technological, and environmental outcomes that entail problem-solving skills and inquiry skills and the values, morals, and ethics involved in decision making so that students can grow to participate more effectively in democratic society.

Positive consequences of the major science curriculum projects of the 1960s included improvement in the quality of teaching, emergence of a wider range of teaching and learning strategies, and increased opportunities for individual and group laboratory investigations. In spite of large classes and poorly planned and equipped facilities, many intermediate and secondary students have had a taste of experimental science. Evidence from surveys in Britain, the U.S., and Canada, however, indicate that in spite of these improvements, many young people suffer from inadequate science teaching. Any attempt to broaden the science curriculum at secondary levels will have pedagogic implications. An attempt will be made to anticipate some of the problems and provide positive planning and development suggestions.

Teaching is demanding partly because many teaching strategies are required to meet various student learning styles, personalities, interests, and aptitudes. How individual teachers cope with this demand depends on several factors including preservice training and inservice opportunities. When the scope of objectives is broadened or the nature of the subject matter moves outside the immediate area of expertise and experience of the teacher, there is increased pressure on the teacher. If teachers are employing a limited number of strategies, for example, content presentation through lecture, then demands of new presentation skills further complicate the change in subject matter and act to cause resistance to proposals for renewal. Given the pervasive change recommended for school science, especially in the area of instruction, a certain amount of resistance should be anticipated, particularly among secondary teachers. A significant amount of time is required and support is needed if teachers are to be expected to support new directions and facilitate rather than subvert or obstruct implementation of new science curricula.

A characteristic of good teachers is self-analysis or the ability to make explicit critical judgments on personal performance. It is necessary that schools not only develop mechanisms in science departments for self-evaluation but also provide for staff development where science teachers observe each other in action and exchange perceptions of their joint strengths and weaknesses.

Science teaching requires the development of a repertoire of teaching tactics and strategies including formal didactic, demonstrations, discussions, small and large group assignments, simulations, gaming, library-based study, community study, individualized learning, ability grouping, laboratory, and field instruction. Each method makes different demands on the teacher. Although teachers use the teach-

ing style or styles they are most comfortable with, lack of experience with some methods may reduce creativity and hinder attempts to encourage teachers to diversify approaches. All teaching methods have legitimacy in the context of the learning task at hand and the aptitudes and aspirations of those who hope to learn. Support for teacher inservice, observation and discussion with student interns who may be learning and experimenting with different methods, or required attendance at workshops and conferences during professional days may be useful. However, it seems likely that at least an initial conserted inservice thrust is required when new curricula are introduced.

Overreliance on any one teaching style, didactic or heuristic, can lead to a set of responses on the part of students that may run counter to the intentions of the teacher. For example, an experimental investigation that is open ended for some students, for example, those with an internal locus of control, may be seen as an intolerable waste of time by others, for example, those with external locus of control.

In general, greater flexibility on the part of science teachers, implied by the broadening of content of the proposed new science curriculum, is required in selection of optimum teaching styles and strategies.

Teachers must also be attentive to the role of language in teaching and learning. In elementary science there has been a tendency to require students to record their experiences in laboratory or field as formal records that do not reflect the nature of individual experience and avoid the use of the personal pronoun, the present tense, and many of the adjectives and adjectival phrases used in everyday speech, thus removing scientific experience from the everyday experience of the child and inhibiting learning (Association for Science Education, 1981). This is not intended to downplay the degree of precision necessary in reporting scientific data but to suggest that more flexibility in the type of language used would act to permit descriptions of affective experiences. Teachers should create opportunities for students to read about science and to discuss their work with each other and with their teachers. Reading and talking are as important as listening, doing, and writing. It is important to provide ample opportunities for young people to articulate their experiences in their own words. This opportunity to practice language skills in science is consistent with the emphasis of language across the curriculum and the development of communication skills. In the long run, scientific objectivity and understanding must develop from a firm base of personal experience and the consequent "search for words" that will encompass and express that experience. The learning of rote definitions by students is meaningless unless the students can use the words in the context of a problem or experiment or demonstrate in some other way a real understanding of the terms used in science.

These suggestions for diversification of instructional strategies are necessarily brief in a broad paper such as this. More intense investigation of the details of individual strategies for science classrooms must precede implementation of new

science curricula. Obviously, teacher support through inservice can greatly facilitate the implementation of a new set of curriculum materials, particularly when some fundamental shifts in instructional methodology are required.

Evaluation

Evaluation as a process of valuing the worth of something or someone based on information and personal values is so broad and complex that it cannot be comprehensively discussed within a document relating science education policy. General aspects of evaluation in formal education will thus be considered in relation to what has been learned from research and experience in evaluating science in schools. The focus of this section will be to attempt to determine what methods of evaluation are most appropriate for science teachers at various levels of education.

Most people and many teachers tend to associate evaluation with testing and usually with objective tests that attempt to measure students' knowledge and understanding of science. Evaluation of students can involve a variety of assessment strategies, and evaluation in the broadest educational sense should include two other elements essential to effective science teaching--the program and the teacher. After examining a number of factors relating to student evaluation, both program evaluation and teacher evaluation will be discussed.

Student Evaluation

Measuring what students have learned is not easy. Evaluating science learning for purposes of teacher information, student feedback, or providing a reference grade is time consuming because it requires careful and thorough planning and execution. Responsibility and accountability are involved as teachers communicate with parents and the community about the results of progress. Evaluation is a key component of curriculum in that it must take into account all the goals and objectives of the science program while stressing the processes, information, and attitudes that the teacher emphasizes during instruction.

Teachers incessantly complain that testing and evaluating students is the least desirable aspect of their professional experience. They often make use of readily available techniques and materials and do not devote a great deal of time to systematically analyzing the results of testing in terms of implications for future instruction. Students also complain about tests, are anxious about test-taking, and argue that tests don't really assess what they've learned. However, the educational system has not found a more valid and reliable method to give direction to student learning. In recent years a newer, broader, less formal view of evaluation has

resulted in a number of effective evaluation strategies that provide more comprehensive and accurate feedback on student progress to teachers, students, and parents.

Science programs that espouse a wide range of goals and objectives must provide teachers with guidance in terms of varied and balanced techniques for assessing the growth of student attitudes, thinking processes, and information levels. Most familiar are the formal summative approaches exemplified by midterms, final standardized, and/or teacher-made tests or end-of-chapter review tests which occur after teaching and learning have taken place. Teachers often want to discover what they did to facilitate or hinder learning and attitude development. Many creative alternatives to formal tests were developed by the curriculum project teams of the 1960s (Welch, 1979). These innovative programs emphasized thinking skills and produced different evaluation strategies to evaluate a wider range of processes and knowledge levels than their more traditional counterparts. For example, conventional true/false tests were inappropriate for assessing students who had been following a curriculum such as S-APA or ESS at the elementary level, or BSCS or PSSC physics at the secondary level (Klopfer, 1971; Stake & Easley, 1978). Research systheses support Arons' (1983) contention that these interesting, imaginative, and educationally sound materials developed by the science curriculum committees of the 1960s can provide excellent sources of materials for development and evaluation of a much wider range of student abilities than traditional curricula (Bredderman, 1983; El-Nemr, 1979; Shymansky, Kyle, & Alport, 1983; Weinstein, Boulanger, & Walberg, 1982). Educators who are looking for alternatives to traditional tests should examine the evaluation programs of the "alphabet science curricula."

In addition, there are a large number of published and unpublished science tests and lists of science tests (see Beard, 1971; Buros, 1978; Mayer, 1974; Tobin & Capie, 1981; Wall & Summerlin, 1973). Teachers were also encouraged to construct their own tests. Hastings and Stewart (1983) advise that teacher-made tests should be used with caution because of validity and reliability problems. The lack of use of some standard psychometric procedures in the development of some widely used tests of innovative curriculum projects such as the Test of Integrated Process Skills (Dillashaw & Okey, 1980), the Basic Science Processes Test (Beard, 1971), and the Understanding in Science Test (Tisher & Dale, 1975) means that these measures should also be used cautiously. Whatever the format, it is important that tests be appropriate to objectives and teaching emphases. The evaluation format must also reflect an understanding of students' developmental levels, reading abilities, and prior experiences (McDermott, 1982; Minstrell, 1982; Peterson et al., 1984; see also Shayer & Adey, 1981.)

Teachers must decide as they develop evaluation instruments whether or not they wish to use criterion-referenced tests. Although these tests are commonly used, there is recent evidence which suggests that the mastery approach is more effec-

tive at facilitating learning (Bloom, 1971; Dillashaw & Okey, 1983; Dunkleberger & Heikkinen, 1983).

Testing student cognitive processes and achievement is not the only way to evaluate students. The following list from Simpson and Anderson (1981) summarizes alternative evaluation techniques and gives examples of each:

	Action	Opportunities to Observe
1.	What do students say?	Class discussion Oral reports, panel discussions Informal conversations during laboratory work, field trips, and extra curricular activities
2.	What do students produce?	Results in laboratory and on research projects Construction of equipment and displays
3.	What do students write?	Written home work Reports of laboratory work and research projects Reports on field trips, interviews, and outside reading Quizzes and tests
4.	What do students do?	Choose or ignore science-related articles, books, television programs, and other forms of education and entertainment Choice of hobbies and careers Changes in habits such as eating a more balance diet or getting regular exercise

(see also Abruscato, 1982, p. 71; Carin & Sund, 1980, p. 282; Appendix 4).

Within proposals for new approaches to science teaching, it is assumed that data such as those listed above can be used to more completely and accurately assess students. Some of the methods that involve student attitudes and interests are believed by many teachers to be inappropriate evidence for determining grades. However, research is beginning to demonstrate that attitudes and interests play a major role in student learning (Gardner, 1975; Levin & Fowler, 1984). Although it is acknowledged that attitudes are more difficult to measure than achievement (Munby, 1983), surveying students' attitudes and interests can play a major role in creating a climate where good science teaching can take place (Marshall, 1984; Peterson et al., 1984). While some caution is advised in the use of attitude surveys, as it was in the case of teacher-made tests, Peterson et al. (1984, p. 207) suggest the following questions as useful considerations in attempting to assess attitudes and values:

Do your students discuss their work with one another?

Do they initiate any new activities in class?

Are they resourceful in finding out what they desire to know?

Are your students curious? Do they continue to explore unassigned topics when they are out of the classroom?

Can your students cope objectively with differences of opinions? Can they express their opinions of right or wrong without letting peer pressure influence them?

Do your students listen to one another?

Do they critically question ideas to attain deeper understandings?

Are they creative and flexible in problem solving?

Are they self-motivated?

Are they able to recognize contradictory evidence or opposing viewpoints?

Other useful measuring devices include Klopfer's (1976) grid which shows how Bloom's affective domain corresponds to science phenomena and Blackwood and Porter's (1968) observation checklist. Both are found in Appendix 5. Although at present less direct means must be used to determine the extent to which affective goals have been achieved, curriculum materials results from reformulation of science programs require that affective behavior be a significant component in a total evaluation of the learner.

The evaluation of psychomotor skills can occur during laboratory, field, or hands-on activities by observing student skill in manipulating equipment or materials such as animals or plants, chemicals, or various measuring devices. Few criteria have been developed for evaluating psychomotor skills. However, Simpson's (1972) taxonomy and Tannenbaum, Stillman, and Piltz's (1965) checklist are useful beginnings (see Appendix 6). Psychomotor skills can be important ways to gain new knowledge and should be attended to in the evaluation of science (Petersen et al., 1984). (See Collette & Chiappetta [1984] for a sample checklist used to assess psychomotor objectives.)

Decision making is an important recent addition to the goals of science teaching. The decision-making process requires students to acquire knowledge and values that apply to a particular personal, social, or environmental problem. They must access information, analyze, evaluate, and synthesize long and short-term consequences of following alternative courses of action or nonaction. Teachers can

evaluate the degree to which students present appropriate knowledge, use the best sources of information available, evaluate costs and benefits and consequences of alternative courses of action, and decide how to resolve the issue or problem (Peterson et al., 1984).

A concrete example of a science curriculum that demonstrates how objectives can be related to science attitudes, to rational and creative thinking processes, to psychomotor skills, and to achievement of scientific knowledge are evaluated using detailed criteria is provided in Appendix 7.

Program Evaluation

Assessing the effectiveness of the curriculum is an important component of evaluation. Many teachers instinctively evaluate the latest science class and make mental notes about what was satisfactory and what could be altered. Stenhouse (1975) urges that one significant way to improve teaching is to have teachers be more systematic about evaluating their actions and the consequences from the point of view of a practicing researcher. Careful examination of discrepancies between anticipated and actual outcomes become more apparent. These discrepancies are not viewed as personal inadequacies but as research problems to be solved by attempting alternative strategies. Some criteria for evaluating a science program both formatively and summatively are found in a sample of guidelines in Appendix 8. A great deal more teacher support material on program evaluation and the concept of teacher as researcher must be included in science curriculum guides. Although beyond the scope of this paper, a background document on the topic of program evaluation would be a useful prerequisite to the construction of curriculum documents.

The science curriculum should be continually assessed to determine its adequacy and whether it is meeting the needs of students as future citizens. Science facilities should be evaluated to determine if they are appropriate for the type of science teaching that is taking place. The National Science Teachers Association has published modules to self-assess school science programs (National Science Teachers Association, 1978a).

Teacher Evaluation

Many teachers are interested in receiving feedback about their teaching. Many documents, questionnaires, and guidelines have been published. They were intended to encourage self-examination and discussion. For example, a number of teacher rating instruments have students react to statements pertaining to teacher behavior in areas of planning, management, evaluation, and student-teacher relationships (see California State Board of Education [1978], Collette &

Chiapetta [1984], Peterson et al. [1984], and Appendix 9). Teachers are often able to judge their own performance--some use videotapes or audiotapes to personally examine presentations. Other teachers keep a journal, perhaps begun in internship, of observations--what works, what doesn't. However, peer appraisal and supervisor evaluation is often useful. If the teacher education program has initiated and fostered the self and external evaluation process as basically nonthreatening and for purposes of improving instruction as opposed to merit rating, then a healthy attitude to continual assessment can result.

A potentially useful resource for assessing the overall quality of science education or for planning a provincial science program is now available (California State Board of Education, 1982). Within this handbook, a description and set of questions is provided for each major component of science education. This handbook also provides guidelines and suggestions for considering essential ingredients of effective science programs. See Appendix 10 for a checklist of assessment criteria.

Simply stated, potentially controversial issues cannot continue to be ignored in science courses. Students must receive adequate grounding in subject matter content, but that alone is not enough. If we accept that a legitimate goal of science teaching is the preparation of intelligent voting citizens and knowing what we do about learning and transfer, then science courses must give students practice in applying science knowledge to relevant societal and environmental issues (Hurd, 1986). The following section provides a more detailed rationale for inclusion of such an emphasis in science programs, using environmental education as the example.

Science and Technology-Related Societal and Environmental Issues

The earth as a life support system is deteriorating. This basic premise has governed activities of ecologists and environmentalists for many years. Environmental education was founded more than twenty years ago on this principle. The establishment viewed the movement as an extremist bandwagon that would eventually go away. But, as Clay Schoenfeld, founding editor of the Journal of Environmental Education, warned in the first edition of this periodical, environmental problems should not be viewed as a single clap of thunder, but as a pervasive drizzle--a visionary metaphor for one of the most pressing environmental issues of the 1980s.

The problems have not gone away; they have become more incipient and threatening. The slumbering giant of science education has, with the exception of some small pockets of activity, virtually ignored the problem of lack of relevance in theoretical content-based science until, in conjunction with associated teaching

methods, it has reached a state of crisis. Bybee (1985b) characterizes the crisis in science as an awakening, as the realization by science that ecological systems are being pushed beyond limits of regeneration by resource depletion, land impoverishment, water contamination, and air pollution. Large-scale research and future projections such as the global 2000 report to the President of the United States have caused science educators to reexamine their priorities. For example, if present trends continue, the world in 2000 will be more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now. Serious stresses involving population, resources, and environment are clearly visible ahead. Despite greater material output, the world's people will be poorer in many ways than they are today (Barney, 1980).

The reality of ecological scarcity emerges in the midst of apparent abundance. In a moment of history the problems of ecological scarcity are also converted into controversies surrounding personal, economic, political, and planetary problems. There are many science-related social issues that citizens do not understand, yet they are asked to make decisions on issues such as toxic waste, acid rain, and the use of life-prolonging technologies (Bybee, 1985b).

The crisis in science education is the failure to respond to changes in society and the avoidance of an orientation toward a public understanding of science and technology. There is wide agreement, as cited elsewhere in this report, among science educators worldwide that science programs must present basic concepts and processes in the context of personal and social applications and issues. This aligns closely with views of educators such as Cremin, Goodlad, and Adler (Bybee, 1985b; Hurd, 1986).

Utilization of scientific and technological information in a context of social and environmental problem solving entails not only conceptual skills and logical reasoning but also consideration of personal and social values and ethics and their role in decision making. This emphasis on issues may have connotations which in the public mind are politically sensitive. When a controversial methodology is coupled with a controversial issue such as nuclear power, fluoridation of water, or robotics, which may challenge deeply held ethical positions, objections are raised by those who confuse values analysis and clarification, as a basis for development of autonomous moral reasoning, with indoctrination of a particular set of values. The educational argument against the methodology and content of controversial issues in science classrooms is much more complex than whether or not a teacher should permit, be involved in, or stimulate discussion of particular topics. It involves fundamental questions concerning the purposes of the school and individual conceptions of curriculum. Full presentation of these philosophical issues is beyond the scope of this paper. However, several points that provide a clearer picture of this new emphasis in science teaching are provided to at least set the stage for the debate that will follow in the literature of the next decade.

If the public expects educators to prepare students to make responsible decisions concerning science-related social problems, as informed citizens do, then should schools provide students with opportunities to think about their own beliefs and values? According to Hurd (1986), a serious criticism of science teaching is that students complete courses with a paucity of values essential for responsible decision making or for choosing positive directions for life and learning. Yet action by an attentive public creates problems for administrative authorities by disrupting their efficient procedures and raising political dilemmas (Aikenhead, 1985a). Can students, or adults, grasp the complexities or abstractions of science content to the degree required for public participation? The questions are complex--there are no easy answers or research-based solutions.

It has been suggested that students probably learn more science from television and the media than from school experiences in science. The media presents science as issues--acid rain, toxic waste, cancer treatment, transplants, euthanasia, animal welfare, chemicals in foods, space technology, Three Mile Island, thalidomide, asbestos fibers in insulation, and many others of a local, regional, and global nature. Thus, a key factor in community acceptance of inclusion of controversial issues in school classrooms is clarification of instructional approaches that involve these media. Teaching students a particular set of values is not the objective of teaching as it may be in the media. The aim of teaching science in a social decision-making context is to provide students with opportunities to integrate scientific information into the making of ethical judgments. This assumes reasonably high levels of cognitive ability in students and high levels of instructional ability in teachers.

The reformers of science education are critical of school science teaching because it fails to recognize that there is an ethical principle in science that relates it to human values. If any mistake was made in the 1960s it was to orient science programs exclusively to the development of future college-bound scientists and engineers. The programs were purged of any orientation toward a public understanding of science and technology (Bybee, 1985b). As Jerrold Zacharias, MIT physicist and originator and developer of PSSC physics reported in testimony before a U.S. House of Representatives Sub-Committee on Science and Technology, "We had aimed only at the college-bound and college students because we could not do everything at once" (Yager et al., 1983).

Clearly, in discussing controversial issues with students, teachers must consider developmental level related to moral development theory in the same responsible manner in which the school assumes cognitive development theory is considered in the presentation of subject matter content. Moral concepts and attitudes acquire meaning only in late childhood and adolescence and require the extensive background of cognitive growth and social experience associated with the age factor (Hoffman & Hoffman, 1964; Kohlberg, 1973; Piaget, 1932). If a child has not yet reached moral autonomy, teachers can have profound effects on that child's values. It seems acceptable that dominant cultural values are inculcated as

opposed to indoctrinated by schools before the age of moral autonomy (which, as every parent knows, develops gradually and differentially) (Hall & Davis, 1975). What a study of controversial issues attempts to encourage is the development of mature and autonomous decision making among learners capable of higher levels of cognitive and moral reasoning and capable of behavior which is characterized by a personal value system. Decision making, as part of a group valuing process, can be encouraged at all ages. This experience can expose learners to many different views based on values which can then be subjected to objective verification at the appropriate developmental level (Polanyi, 1958). A solid personal system of moral values and ethics is a foundation for social decision making.

In the development of school science programs, curriculum development teams can exert control over the nature of the issues discussed. At elementary levels, decision-making strategies related to appropriate issues using appropriate teaching techniques are available or can be developed. At the middle years level, student decision-making modules can be adapted to curriculum materials from recommended resource texts and other sources. At the secondary level, value and ethical issues that arise when science and technology are elements of societal or environmental issues can be approached as ethical dilemmas that result from alternative viewpoints or approaches. The key to success in teaching controversial issues is to expand teachers' repertoires of instructional strategies through teacher training and inservice to include techniques in individual and group problem solving and decision making. Many new materials are available for this purpose.

The following point is emphasized by Collette and Chiappetta (1984, p. 215) in their text on science instruction in middle and secondary schools, in the chapter on science and societal issues for discussion, inquiry, and values clarification:

> The decision to include discussions of societal issues within the framework of science instruction does not occur without some essential changes in the teacher's instructional approach. This point cannot be over emphasized, since (sic.) a number of curriculum orientations have failed because the teacher simply "mentioned" and briefly discussed a few societal issues subsequent to his or her traditional substantive lecture. One must remember that the purpose of including societal issues in science instruction is to give students an opportunity to clarify their own values and make informed decisions with regard to everyday social problems. This goal can never be accomplished unless the teacher provides the opportunity for students to discuss social issues, inquire into the relevant scientific principles and concepts, and reassess or reaffirm their values. Such opportunities can be provided through a number of easily performed, but essential, adaptations in classroom organization and evaluation.

These authors then devote about 30 pages to discussion of instructional approaches, unit design, evaluation, scientific and social relevancy, student age and ability, and content concerns followed by eleven appropriate social issues for

discussion in earth, biological, chemical, and physical sciences. Another source of practical curriculum and instruction suggestions is Simpson and Anderson (1981, pp. 431-483). A number of first generation science-technology-society curriculum materials are found in McConnell (1982), Gaskell (1982), and Aikenhead (1985a). (See also Peterson et al., 1984; Ziman, 1980.) (See Connelly et al., 1985, p. 391 for Alberta's policy statement on controversial issues.)

Two decision-making models are included as Appendix 11 for discussion reference (Collette & Chiapetta, 1984; McConnell, 1982).

Pitfalls or potential dilemmas for the social decision-making component of science-technology-society science education are thoughtfully presented by Aikenhead (1985a), Baer (1981-82), McConnell (1982), and Roberts (1982).

Integration of Science and Other School Subjects

The report of the Core Curriculum Advisory Committee (Saskatchewan Education, 1986) recommended a core curriculum which included six areas of study. The intention was that each area of study should reinforce other areas as all areas facilitate the development of common essential learnings and the goals of education. This section of the report on science education provides a review of literature that addresses the relationship between science and other subjects taught in schools.

In some ways the tendency to interrelate school subjects at the elementary level is natural given the character of the learning environment intended for elementary classrooms. However, integration of subject material requires a higher level of teacher practice than teaching by subject. Integration in science assumes that teachers have requisite knowledge and background in science and a positive inclination to teach science. According to a number of researchers both of these are false assumptions with respect to elementary teachers (Bethel, Ellis, & Barufaldi, 1982; Bethel & Hord, 1982). At middle and secondary levels, science is taught as content or structure of the discipline because, teaching as they were taught, teachers don't know how to blend science with other subjects and only casually discuss mutual reinforcement of subjects. The literature, which in the case of subject interrelationships is ahead of practice, is encouraging. Many individuals and groups have provided the stimulus and suggestions for intersubject reinforcement, and the most recent research on this topic indicates that the attempts to integrate learning across subject areas has produced positive effects on student learning.

In the area of language arts, research indicates that a hands-on, activity-oriented science program can facilitate development of language arts skills (Lucas & Bur-

lando, 1975; Wellman, 1978). Reading and science emphasize the same process skills. When teachers work to develop intellectual or thinking processes in science activities, reading processes are simulataneously being developed (Carter & Simpson, 1978; Mechling & Oliver, 1983; Simon & Zimmerman, 1980). For example, when students are observing or classifying in science, they are developing abilities in vowel-consonant discrimination; in letter, letter blend, and syllable recognition; and in paragraph interpretation. Science processes are essential to logical thinking and thus form basic skills for learning to read (Barufaldi & Swift, 1977).

There is evidence that reading readiness can be enhanced by science process skills (Ayers & Mason, 1969; Barufaldi & Swift, 1977; Esler & Anderson, 1981; Nicodemus, 1968; Renner, 1971; Renner, Stafford, Coffia, Kellogg, & Weber, 1973; Rowe, 1968; Webber & Renner, 1972). More specifically, experiences in science using a process approach enhance children's ability to conserve quantity, an essential factor in reading readiness (Ayers & Ayers, 1973; Renner, Stafford, Lawson, McKinnon, Friot, & Kellogg, 1976), to develop perceptual skills (Neuman, 1974), and to develop concepts, vocabulary, and oral language skills necessary for learning to read (Wellman, 1978).

Science experiences can enhance oral and written communication skills when actual practice in these skills occurs as part of the science experience. Activity-based science can provide rich experiences for writing (Catha, 1977; Fraizer, 1983; Knight, 1977; Mechling & Oliver, 1983; Reid & McGlathery, 1977; Simon & Zimmerman, 1980). Stulp (1976) suggests that interpersonal communication between teacher and student can be improved through science-related writing. Similar findings were reported by Huff and Languis (1973) and by Roderiguez and Bethel (1983). Rowe (1974a, 1974b) found that language and logic development were enhanced by science teachers who used wait-time in student-teacher inquiry discussions.

Science experiences also appear to enhance language development in students with special needs such as those with different ethnic backgrounds (Horn, 1966; Stemmler, 1966) and those with physical disadvantages (Boyd & George, 1973; Bybee & Hendricks, 1977; Linn & Peterson, 1983; Long, 1973).

Experiences in science can provide motivation (Graham, 1978), reinforce concepts learned in activities (Thier, 1970), help students to locate and organize information for reporting (Wright & Hounshell, 1978), and help them to check the validity of their own findings (Carin & Sund, 1980).

Although fewer relationships are found between language arts or English and science disciplines at the secondary level, findings at intermediate levels or middle years suggest that science instruction results in vocabulary enrichment, increased verbal fluency, enhanced ability to think logically, improved concept formation and communication skills (Wellman, 1978), and stimulation of creative

writing (Leeper, 1984). With all of the natural connections that have been demonstrated between writing and science, it is surprising that a recent survey of secondary science teachers reveals that they rarely use writing to stimulate or reinforce creative thinking. More than teachers of any other subject, secondary science teachers rely on writing only for testing how well students have mastered content (Applebee, 1981).

The development of skills in logical reasoning and problem solving is a goal of both science and mathematics instruction (National Council of Teachers of Mathematics, 1980; National Science Teachers Association, 1983a). According to Almy (1966), science and mathematics reinforce each other in the learning environment, thereby facilitating cognitive development. Through the use of mathematics in investigations, students gain better insight into science concepts and principles (Koballa & Bethel, 1984). It is also hypothesized that science experiences can enhance learning of mathematics by relating abstractions of mathematics to meaningful experiences in science (Shann, 1977). The research tends to substantiate this. For example, a number of studies have demonstrated that a variety of science experiences contribute to the development of cognitive operations such as conserving number, substance and length, one-to-one correspondence; ordering; seriating; and classifying (Almy, 1966; Ayers & Ayers, 1973; Ayers & Mason, 1969; Carin & Sund, 1980; Renner, 1971). Conservers experience greater success in learning both mathematics and science skills and concepts. Similar effects have been reported for adolescents (Sunal, 1982; Tipps, 1982). According to the Tipps (1982) study, the strongest predictor of formal reasoning, other than age, was achievement in science.

Research suggests that mathematical aptitude influences science-related problem solving (Champagne & Klopfer, 1982a; Gabel & Sherwood, 1983; Larkin & Brackett, 1974). Science experiences on the other hand enhance mathematical problem-solving abilities of elementary (Coffia, 1971; Shann, 1977) and secondary students (Friend, Wisotsky, Sega, & Petosa, 1984; Gabel & Sherwood, 1983; Gabel, Sherwood, & Enachs, 1984). Obviously, considerable overlap exists between a number of science and mathematics process skills and concepts.

Given the current trend in science education toward a more broad-based societal emphasis, it is interesting that a number of educators are attempting to justify mathematics on the same grounds and, in fact, advocate an integration of mathematical problem solving within a science framework that focusses on real world problems (Grouws & Thomas, 1981; Mechling & Oliver, 1983; National Council of Teachers of Mathematics, 1980; Reed, 1971).

Secondary school teachers appear to require more help with ideas related to taking advantage of mutual reinforcement of subjects. They do not know the literature, do not see the need, and are not prepared to expend the additional energy. Thus, examples of attempts to examine interrelationships are insightful (Hart, Turner, & Booth, 1982).

Although less research has been conducted on the relationship between science and other subjects, some interesting activities have been described for social studies, health, and fine arts (aesthetic education).

The new emphasis proposed for science education involves inclusion of a societal context. This would provide science and social studies with a common operational base in broad areas of knowledge, values, and decision-making skills (Gennaro & Glenn, 1975; National Council of Social Studies, 1984; National Science Foundation, 1983; Penick & Meinhad-Pellen, 1984; Social Studies Education Consortium, 1980). Given the research indicating that factors other than school contribute significantly to students' science knowledge; that there is little or no growth in science concept mastery over the secondary school years (Miller, Suchner, & Voelker, 1980); that 90% of college-bound and 96% of noncollege-bound high school students were unattentive to science (Voelker, 1982); and that a majority of 13 and 17 year olds have no understanding of the relationship between science, technology, and society in areas of energy, food production, population growth, and environmental problems (National Assessment of Educational Progress, 1979); changes are clearly required. Both science and social studies educators are aware of the failure of schools to prepare students for making informed and responsible decisions regarding social issues, science, and technology (Koballa & Bethel, 1984). Both groups stress that students must be taught, through science and social studies or integrated courses, to understand, appreciate, and appraise the impact of science and technology on society and environment (Charles & Samples, 1978; Hurd, Bybee, Kahle, & Yager, 1980).

Programs have been developed or are under development to assist teachers to implement science/social studies-related studies (see American Forest Institute, 1977; Biological Sciences Curriculum Study, 1977; Fowler, 1975; Harshman, 1977; Hickman, 1977; Hurd, 1976; McInerney, 1979; Seymour, 1981; Western Regional Environmental Education Council, 1983). In addition, the National Science Teachers Association's Search for Excellence program has identified exemplary programs that foster the science-technology-society emphasis (Penick & Yager, 1983). Criteria for identification included a focus on one of the following themes: energy, population, human engineering, environmental quality, natural resource use, defense, sociology of science, and technological development (Penick & Meinhand-Pellen, 1984; Piel, 1981).

Koballa and Bethel (1984) suggest that, given good materials, science and social studies relationships are easily incorporated into elementary programs using a science in society theme because the same teacher is typically responsible for both subjects. The establishment of a similar relationship at middle or secondary levels is more difficult but worth the effort (Kirman and Nay, 1975; Rosenthal, 1979).

Health, an obvious subset of science, has in the assessments of the 1970s received similar criticisms to those reported for science (Hochbaum, 1978; Weiss, 1978). Content overlap between health and science in new curriculum materials is such

that when topics such as human genetics, disease, food and nutrition, and human body systems are introduced in elementary curricula, subject distinctions are hazy (Mechling & Oliver, 1983; Weiss, 1978; Yager, 1981b).

Involving students in science process skills and teaching them thinking and decision-making skills can make health more than the boring and repetitious subject reported by students (Haggerty, 1977). Several new innovative programs now available for elementary and secondary students emphasize individual responsibility and thinking and decision-making skills (Biological Sciences Curriculum Study, 1983; Health Activities Project, 1982). Health and science are designated by the Saskatchewan core curriculum advisory committee (Saskatchewan Education, 1986) as separate areas of study and new health curriculum guides are being pilot-tested. However there is excellent potential for integration with science especially in a science-technology-society context.

Aesthetic education will have more potential for integration with science if a science-technology-society-environment emphasis is introduced to broaden the curriculum base of science. The literature indicates that when aesthetic education areas of art or music and science are taught in a related manner, both areas benefit (Hadary & Cohen, 1978; Mechling & Oliver, 1983). In both science and art, for example, common processes of observing, describing, manipulating, and demonstrating are integral to learning by doing--active participation (Hadary & Cohen, 1978). Art and science have been demonstrated to have mutual benefits in that science is viewed from an aesthetic viewpoint and art as requiring precision and careful observation using all of the senses. At both elementary (Chetelat, 1979) and secondary levels (Karen, 1978; Matray & Knorr, 1980), relationships between art and science have enhanced the experience in both areas for students.

Many relationships between music and science had been demonstrated in existing curricula such as the ESS units on musical instruments, whistles, and strings (Elementary Science Study, 1969). The applications of physical principles to areas such as music are exactly the kinds of "societal" experiences advocated for the sciences by the science-technology-society-environment emphasis. Motivation and practical application of abstract physical principles are complemented by a more detailed understanding of some of the cultural aspects of society (Mechling & Oliver, 1983; Willems, Willems, & Stacy, 1981).

Obviously, much more could have been written about interrelationships between science and other core curriculum areas. The literature surveyed here is intended to stimulate curriculum developers who are searching for ways to mutually reinforce common essential learnings among core curriculum areas. If integration across subject areas is accepted by policy makers and educators as a legitimate goal of education, then the inclusion of the science-technology-society-environment emphasis in science education can facilitate the ability of science to satisfy this goal.

Science and Related Areas

Victor Hugo once wrote, "There is no force greater than that of an idea whose time has come." For over twenty years environmental educators have been trying to communicate to the educational system that an important crucial element was missing in the education of children and adults.

Recommendation 96 of the Stockholm Conference on the Human Environment called for development of environmental education as one of the most critical elements of an attack on the world's environmental crisis. This new environmental education was to be broad based and strongly related to the basic principles outlined in the United Nations Declaration on the New International Economic Order.

Environmental education, although relatively new as an educational endeavor, has ancient intellectual roots. Recent unprecedented environmental insults and the realization of rapid depletion of natural resources has prompted the suggestion that unless some current trends are reversed, hunger, conflict, and widespread human suffering are imminent. Inherent in environmental education is a deep-seated philosophic belief that we must reexamine the way that society looks at problems and makes decisions. Educational systems have a responsibility in development of new understanding and an acute awareness of humanity's relation to its environment.

According to the Belgrade Charter (UNESCO-UNEP, 1976) the ultimate goal of a global framework for environmental education is environmental literacy which is characterized by a new global ethic--an ethic which espouses attitudes and behavior for individuals and societies which are consonant with humanity's place in the biosphere and which recognizes and sensitively responds to the complex and ever-changing relationships between humanity and nature and between people. A new concept of economic development must include the conditions of maximum reduction in harmful effects on the environment and design of environmentally appropriate technologies. Those national and regional policies aimed at maximizing economic output without regard for its consequences on society and on the resources available for improving the quality of life must be questioned. Individuals must assume a personal ethic reflecting commitment to improving the quality of environment and of life.

The reform of educational processes and systems is central to development of environmental literacy and competence that reflects this underlying ethic of respect for the planet. According to Harvey (1977), this ethic, as an educational goal, implies that teachers will adapt their instruction to assist individuals in becoming knowledgeable about the environment and its associated problems and, through understanding, to become motivated to work, individually and collectively, toward

maintaining or improving the quality of the environment and the quality of life for its inhabitants.

This goal statement implies that students must not only have information about the environment but also the skills that will permit them to function as change agents in society. Ramsay, Hungerford, and Tomera (1981) conclude from their research in environmental action strategy training that specific training in and application of environmental problem-solving skills constitute a unique instructional component which, when combined with environmental information and values, tends to encourage successfully independent overt environmental behavior. Certain instructional components, crucial to the development of responsible, competent citizens, should be a part of every individual's educational experiences.

Certain curricular goals have been established to develop environmental literacy and these should provide guidelines for the development of instructional materials for environmental education. The following goals from Hungerford, Peyton, and Wilke (1980, pp. 43-45) are intended to provide a framework from which specific instructional objectives could be written.

The Goals for Curriculum Development

Level I. Ecological Foundations

This level seeks to provide the learner with sufficient ecological knowledge to permit him/her to make ecologically sound decisions with respect to environmental issues. The Ecological Foundations Level would minimally include the following conceptual components:

A. individuals and populations

B. interaction and interdependence

C. environmental influences and limiting factors

D. energy flow and materials (biogeochemical cycling)

E. the community and ecosystem concepts

F. homeostasis

G. succession

H. man as an ecosystem component

I. the ecological implications of man's activities and his communities

Level II. Conceptual Awareness--Issues and Values

This level seeks to develop a conceptual awareness of how individual and collective actions may influence the relationship between quality of life and quality of the environment and, also, how these actions result in environmental issues which must be resolved through investigation, evaluation, values clarification, decision making, and finally, citizenship action.

Goals at this level are to provide opportunities for learners to conceptualize:

A. how man's cultural activities (e.g., religious, economic, political, social, etc.) influence the environment from an ecological perspective

B. how individual behaviors impact on the environment from an ecological perspective

C. a wide variety of environmental issues and the ecological and cultural implications of these issues

D. the viable alternative solutions available for remediating discrete environmental issues and the ecological and cultural implications of these alternative solutions

E. the need for environmental issue investigation and evaluation as a prerequisite to sound decision making

F. the roles played by differing human beliefs and values in environmental issues and the need for personal values clarification as an integral part of environmental decision making

G. the need for responsible citizenship action (i.e., persuasion, consumerism, legal action, political action, ecomanagement) in the remediation of environmental issues

Level III. Issue Investigation and Evaluation

This level provides for the development of the knowledge and skills necessary to permit learners to investigate environmental issues and evaluate alternative solutions for remediating these issues. Similarly, values are clarified with respect to these issues and alternative solutions. Goals at this level are presented in two components.

Component A: Goals for Component A are to develop in learners:

A. the knowledge and skills needed to identify and investigate issues (using both primary and secondary sources of information) and to synthesize the data gathered

B. the ability to analyze environmental issues and the associated value perspectives with respect to their ecological and cultural implications

C. the ability to identify alternative solutions for discrete issues and the value perspectives associated with these solutions

D. the ability to autonomously evaluate alternative solutions and associated value perspectives for discrete environmental issues with respect to their cultural and ecological implications

E. the ability to identify and clarify their own value positions related to discrete environmental issues and their associated solutions

F. the ability to evaluate, clarify, and change their own value positions in light of new information

Component B: Goals for Component B are to provide learners with opportunities to:

G. participate in environmental issue investigation and evaluation

H. participate in the valuing process in a manner as to permit the learner to evaluate the extent to which his/her values are consistent with the goal of achieving and/or maintaining a dynamic equilibrium between quality of life and quality of the environment

Level IV: Environmental Action Skills--Training and Application

This level seeks to guide the development of those skills necessary for learners to take positive environmental action for the purpose of achieving and/or maintaining a dynamic equilibrium between quality of life and quality of the environment. Goals at this level are presented in two components.

Component A: The goal for Component A is to develop in learners:

A. those skills which will permit them to effectively work toward ends which are consistent with their values and take either individual or group action when appropriate, i.e., persuasion, consumerism, political action, legal action, or ecomanagement

Component B: The goals for Component B are to provide learners with opportunities to:

B. make decisions concerning environmental action strategies to be used with respect to particular environmental issues

C. apply environmental actions skills to specific issues, i.e., to take citizen action on one or more issues

D. evaluate the actions taken with respect to their influence on achieving and/or maintaining a dynamic equilibrium between quality of life and quality of the environment

Examination of these goal statements for environmental education reveals a number of interesting points, some of which are directly related to science education. It should be obvious that the science-technology-society emphasis newly advocated as a solution to the crisis in science education is essentially environmental education without the politically sensitive "environment" label. Inspection of definitions of environmental education published by the North American Association for Environmental Education,conveys the breadth of "environmental" concern--beyond the man and nature theme to full consideration of humans within ecological, political, economic, technological, social, political, cultural, and aesthetic contexts. Environmental education emphasizes active participation in preventing and solving environmental problems and this means science-related societal and technological issues. Science-technology-society science education perhaps places slightly less emphasis on interdisciplinarity (beyond an integrated approach to the sciences); on futures or global issues or studies (although some authors discuss these components as characteristics of science, technology, society); and on prerequisite ecological concepts (although Hurd [1984] and Bybee [1984], two prominent science-technology-society spokesmen, stress the importance of ecological concepts and information). Science-technology-society education has technological overtones which appeal to traditionally conservative business and industrial support groups and thus is politically astute in its approach to the introduction of values and political activist skills within its framework. Lucas (1980) discusses a certain disciplinary chauvinism on the part of service educators who appear to be attempting to reinvent the environmental education wheel under the new label of science-technology-society science education, and fail to draw on an extensive existing literature in an effort to avoid potential pitfalls and problems of experience.

It should also be obvious from examination of environmental education goals that, regardless of the importance of methodologies such as outdoor education, environmental interpretation, acclimatization, and outdoor recreation, these are not a part of the substantive structure of environmental education. However, a number of environmental education goals might be facilitated by these and other methodologies.

Environmental education, by definition and by action, subsumes under its umbrella energy education and conservation education. The ramifications of energy

education, although an important world focus, are similar to those of environmental education (Simpson & Anderson, 1981). In energy education, however, because of the serious energy-related political and economic implications, coherent sets of goals that serve to provide an energy focus within a broad context of environmental education have been developed (see Allen, LaHart, Dawson, & Patterson, 1976).

Fensham and May (1978) suggest that implications of the Belgrade Charter view of education for the environment can be used to define the environmental education component of a core curriculum. They suggest that these implications can guide the selection of content from the various subject disciplines to ensure that the aims of the core curriculum are satisfied. However, before this can happen a major reorientation of the notion of a core curriculum will be required (Lucas, 1980).

Thus, the proposal for science education for Saskatchewan with its greater emphasis on science, technology, society may be viewed as consistent with the ideals and aims of environmental education. It may be considered a step in the right direction in the sense of attempting to move the underlying epistemology toward a global orientation. Whatever form it takes, evolution toward an ecocentric world view, after two decades of defining the educational problem and devising curricular and methodological solutions, is encouraging.

Implications for Teacher Education

Bybee, Carlson, and McCormack (1984) conducted a review of major contemporary reports on education in search of recommendations that might relate to science education. One report examined academic preparation for college--the result of a ten-year effort by the U.S. College Board to strengthen the academic quality of secondary education for all students. The report provides secondary schools with a review of what students need to know and be able to do, that is, the knowledge and skills needed for college as described in surveys of hundreds of teachers. Major competencies related to reading, writing, speaking and listening, calculating, reasoning, studying, and computing are listed. Some are directly related to science.

Students need to understand in some depth the unifying concepts of the life and physical sciences. Students must demonstrate ability to distinguish between scientific evidence and personal opinion; recognize the role of observation and experimentation in the development of scientific theories; ask appropriate questions based on familiarity with laboratory and field work and recognize what is involved in experimental approaches to answering such questions; gather scientific information through laboratory, field, and library work; and organize and

communicate the results obtained by observation and experimentation. College prerequisites include a detailed knowledge of at least one field of science, defined as the earth sciences, one of the new interdisciplinary fields, or one of the traditional ones--biology, chemistry, or physics.

Another influential U.S. science policy commission, the National Science Board Commission (1983) recommended that the number of topics in high school science courses should be drastically reduced. Attention should be directed toward the integration of facts, concepts, and principles within each discipline and with other sources and areas such as mathematics, technology, and the social sciences.

For many years, prominent science educators have stated that science courses cannot be justified at high school level by whether they are preparatory for university-level physics, chemistry, or biology. These courses should, however, be available for individuals contemplating advanced study. For most students, as a part of general education, the overall purpose of the science program should be to increase the scientific literacy of the population as a whole--to help them understand the possibilities and limitations of science and the effects it can have on them, their community, their country, and their world, and to help them become contributing members of society (Hurd, 1986; Thier, 1984).

Many influential individuals and organizations have made recommendations similiar to those just outlined. Teachers typically justify their content and methods in terms of preparation for the next higher level in spite of the well-known fact that the instructors at the next higher level typically assume very little other than an ability to read and write. At postsecondary institutions in Saskatchewan, as elsewhere, basic information is generally provided in introductory courses whether university, technical, or industrial. The pressure on high school teachers to cram content into students so that they will be competitive is largely unjustified, elitist, and unfair to the wide majority of students. This teaching style has led to the present crisis in education and must be changed--probably through teacher preservice, inservice, and, in some stubborn cases, reassignment and turnover. The remainder of this section will review research relating to effective teaching practices and the required adjustments in teacher education.

During the past fifteen years, a great body of educational research has dramatically increased our knowledge of how factors such as instruction are related to knowledge and skill acquisition. Unfortunately, this impressive accumulation of findings has gone largely unnoticed by educators who do not actively read educational periodicals and by the general public (Walberg, Schiller, & Haertel, 1979). However, teachers are the vital factor in improvement efforts (Crandall, 1983). Change will not take place without the support and commitment of teachers (Purkey & Smith, 1982) and principals (Austin, 1979).

Research on educational improvement that has focussed on microeffectiveness or schools with exemplary science programs reveals that several important condi-

tions are necessary. These program evaluations describe teachers who are motivated to create a learning environment conducive to inquiry; are involved in curriculum development and professional organizations; do not have a textbook-oriented program; spend less time lecturing and more time on laboratory and field integration; encourage student action, decision making, creativity, and excitement; challenge students; expect different students to achieve differently; and develop effective communication strategies, all while stressing development of higher level intellectual skills. Teachers gain administrative support by putting in more than the minimal time and by working closely with parents and community leaders (Bonnstetter, Penick, & Yager, 1984; Mechling & Oliver, 1983; Penick 1983a, 1983b; Penick & Yager, 1983; Squires, Huitt, & Segars, 1981; Sweeney, 1982; Yager et al., 1983).

Research that has focussed on microeffectiveness, in terms of teacher function, indicates that teachers must: increase engaged time on subjects such as science because this is a powerful factor in learning (Goodlad, 1983); work with administrators to increase flexibility in time and scheduling of block science periods; actively engage students in learning--or it will not occur; match task requirements to student abilities to foster success and stimulate motivation; and focus on meaningful coverage of material and also on integration of relevant content, science processes, and applications to societal and environmental contexts. Applications to societal issues should become the focus for coverage (Kyle, 1984).

Research indicates that teachers who establish learning environments that are supportive of cooperative learning experiences are more successful in promoting mastery and retention of material and developing more positive attitudes toward the experience than those who provide individualistic learning experiences (Bloom, 1984; Humphreys, Johnson, & Johnson, 1982; Walberg, 1984). Effective teachers actively plan learning experiences. That planning involves thoughtful selection of teaching approaches (Peterson, Marx, & Clark, 1978). Despite recent back to the basics tendencies, an emphasis on basics and direct instruction is not effective in all disciplines or for all students (Gage, 1978; Good, 1979; Rosenshine, 1979). It is extremely important that teachers implement a variety of instructional techniques (e.g., group work, projects, simulations, role play, independent study, brainstorming, classroom discussions) that bear a logical relationship to instructional objectives (Bloom, 1976; Goodlad, 1983).

Effective teaching environments are ones in which students are aware of objectives and receive feedback on progress, get opportunities to physically interact with instructional materials, and engage in varied kinds of activities. Teachers plan instructions and interventions and students have some responsibility for defining tasks (Wise & Okey, 1983). Supervision that supports classroom teachers' efforts to improve instruction by planning instruction as well as content can improve practice where the teacher receives necessary support as long-term (on-going) inservice. This support must be relevant and designed to meet the needs of individual teachers in their classrooms (Boulanger, 1981; Kyle et al., 1982; Shymansky et al.,

1982a, 1982b; 1983; Squires et al., 1981). Smaller class size is also an important variable (Glass, Cohen, Smith, & Filby, 1982).

The rapid accumulation of research on teacher effectiveness has tremendous implications for science teacher preparation and professional development. Inadequate or insufficient training handicaps teachers and, subsequently, their students.

North America is facing a critical shortage of qualified science teachers, especially at the secondary level (Yager, 1984). Similar to the trend in Canada, U.S. teacher training institutions have each graduated, on average, only five science teachers, mostly in biology (National Science Teachers Association, 1982). Many areas report shortages--the overall supply of individuals with science degrees has been falling since 1972 (National Science Foundation, 1982). Associated problems include the large numbers of science teachers leaving the profession for higher paying employment (Hurd, 1983b) and school districts filling science positions with unqualified individuals (Yager, 1984). There is also a growing body of literature on the quality of preservice teacher applicants (Feistritzer, 1983; Hart, Kesten, & Burgess, 1986; Hurd, 1983b). There are recommendations that, in addition to academic screening which appears to be required, other personal and social factors must be part of the selection criteria.

The research on training of teachers indicates that most Canadian provinces and U.S. states rarely require preservice elementary teachers to take more science than is required for the academic component of their undergraduate program (Helgeson et al., 1977). Where there is a requirement of a science and a science methods course, in order not to increase the number of hours in the teacher education program, substitutions are allowed or old standards altered so that teachers are certified without any credits in science (Weiss, 1978). The typical undergraduate sequence of required courses is inadequate (Hurd, 1983b). Even though sets of guidelines have been developed by science associations (American Association for the Advancement of Science/National Association of State Directors of Teacher Education and Certification, 1971; National Science Teachers Association, 1982), most universities and colleges have not followed the guidelines (Feistritzer, 1983).

How teachers get trained in their profession affects both their teaching practices and their attitudes. For example, meta-analysis research has demonstrated strong empirical support for the use of inquiry methods in teaching science (Shymansky et al., 1983). If more teachers were adequately trained in these methods as part of their preservice science education, quality of science instruction would increase (Helgeson et al., 1977). Some teachers' difficulty in teaching by inquiry may be due to inadequate training, (Stake & Easley, 1978). Inservice, however, has been effective (Helgeson et al., 1977). Positive attitude change has been demonstrated by preservice teachers who experienced a hands-on, inquiry-oriented science methods course (Barufaldi, Huntsberger, & Lazarowitz, 1976). Change in teacher

behavior, such as development of effective questioning strategies, observing, and evaluating students, and other behaviors related to teaching science by inquiry have also been reported where teacher training models use inquiry (Heron, Jaus, Neie, Luce, & O'Heron, 1974; Renner, 1976; Tobin, 1980; Yeany, 1975).

Some positive effects of preservice science teacher training can be demonstrated. However, research reveals that teachers perceive existing kinds of inservice to be of little or no value (Bethel & Hord, 1981; Seldin, 1979). Complaints center around lack of direct relevance to classrooms, active participation, input, and a continuous long-term inservice plan. During the science curriculum changes of the early 1960s, little or no attention was devoted to inservice development of instructional strategies or teacher behaviors needed to implement new curricula. Many teachers, striving to keep abreast of new developments and stay current in science knowledge, require new inservice efforts directed at instruction (Weiss, 1978). It is important for government to assume leadership roles through funding of elementary and secondary science inservice--local school districts do well to maintain quality at current levels of funding. Inservice must be viewed as continuous professional development (given preservice inadequacies). Teachers must have input and incentives to upgrade and update, and administrators must cooperate. Teachers must demand that effective science inservice take place (Bowyer, 1984). Some excellent plans and models exist for improving the quality of inservice and staff development, a topic that deserves more intensive investigation than the scope of this study permits (for example, see Bethel & Hord, 1981; McCarthy, 1982; Mohlman, Kierstead, & Gundlach, 1982; Wilsey & Killion, 1982; Wood, McQuarrie, & Thompson, 1982; Wood, Thompson, & Russell, 1981).

Included as Appendix 12 are the National Science Teachers Association's (1983b) recommended standards for the preparation and certification of teachers of science. Although no similar Canadian documents exist, some recent recommendations of British Columbia science teachers for revising teacher education programs strongly support the recommendation of the British Columbia Science Assessment that faculties of education should revise teacher education programs as needed to ensure that all preservice elementary teachers experience science study to a minimum of a 3-unit course, take a course in science teaching methodology, and emphasize techniques and topics identified by teachers to be most inadequately emphasized in preservice training (Stronk, 1985; Taylor, 1982).

Although educational research may inform educational practice (Baker, 1984), the policy climate of the 1980s appears to have been shaped by the symbols of consensus, not breakthroughs in educational research (Yudorf, 1984). If there is one point of consensus backed by research that may be considered the focus for change in science education, it is the attitudes, perceptions, and behaviors of the classroom science teacher. Brooks and Matthews (1981), reacting to the 1981 Yearbook of the Association for the Education of Teachers in Science (Ochs, 1981), indicate that the characteristics of classroom teachers far outweigh any effects that

come about as a result of changes in curriculum as far as actual changes in what is taught are concerned.

Teachers are a product of their experiences. Whether most teachers, who have experienced only the expository mode or a structure of the disciplines emphasis (Roberts, 1982), can adapt as a result of inservice remains problematic, notwithstanding (Erb, 1981). Entry into secondary science teaching usually comes after an extended period of training and career orientation towards the sciences themselves followed by short periods of contact with science educators "integrated" within school experiences which involve extensive socialization and acculturation into the idealized norms of science teaching status quo. Affected by characteristics of social influence, such as perceived authority, relative status, control of important rewards or sanctions, and group or peer acceptability, neophyte science teachers develop a self-concept of internal career that influences decisions about appropriate behavior. The importance of the special knowledge base as a claim to professionalism is important to the individual's sense of legitimacy and competency as well as providing a somewhat tenuous link to the scientific community. A less well-defined component of the knowledge base is the collection of more tentative theories of professional practice dealing with principles of learning and teaching. For many science teachers, identification with science is preferable to the ill-defined, complex, probabilistic identification with education, teaching, and students. This orientation has an effect on a secondary science teacher's perception and response to communications for the profession. Science teachers accept science and scientists as their sources of authority and have failed to create a necessary but distinct collegial authority based on expertise in pedagogy. Until this critical aspect of socialization and acculturation is dealt with in theory, research, and practice, effective inservice may be a "pipe dream" (Ukens, 1983). We must begin to work on values, beliefs, self-imagery and areas of social influence on science teachers before they will be ready to honestly and openly receive advice from pedagogical authority of any sort (see Medvitz & Watson, 1979).

One mechanism that may force teachers to conceptualize and communicate their assumptions and conflicting conceptions of curriculum may be deliberative inquiry into science education. One major point of discussion would be the development of a consensus about the goals of science teaching. Without consensus about what the goals of science teaching should be, it would be impossible to design a program to prepare science teachers to function effectively (James, 1984). If scientific literacy becomes the goal of science teaching as numerous educators and groups suggest (Hurd, 1983a; Science Council of Canada, 1984), then it must receive greater attention in teacher education. If technological literacy is a common essential of learning in Saskatchewan (Saskatchewan Education, 1986; Shamos, 1983), this must also be a focus of science teacher education. Duschl (1983) indicates that science teachers need to learn science in a manner consistent with the way they are expected to teach (Mechling et al., 1982). This has implications for prerequisite arts and science as well as education courses for

preservice teachers. For example, preservice teachers need exposure to multidisciplinary approaches to science (James, 1984), field and laboratory instructional design and evaluation methods, the latest technology including microcomputers and videodisc media, curriculum design, alternative instructional strategies, and investigative teaching. They also need competence in information access and analysis (Gallagher, 1984), the use of community resources for applications to society (Dede, 1983), and handling special needs students such as the handicapped and gifted (Trowbridge, 1984). They need to develop a frame of mind that recognizes the inevitability of change, and they must be capable of reacting constructively (Stenhouse, 1975). Gallagher (1984) stresses the need for attitude development so that the total range of expanded objectives for scientific literacy can be adequately addressed.

Individual Needs

People differ. There are many different kinds of children, with a great variety of abilities, needs, and interests and an even greater variety of educational and life opportunities. Literature supporting claims that learners vary widely and that instruction has a differential effect can be found in almost every issue of every professional journal. However, the many varieties of learners are largely taught by identical instructional methods (Andersen, 1983).

Research has demonstrated that when the kind, quality, and quantity of instruction are varied according to learner needs, almost all learners achieve mastery of the subject (Bloom, 1976). The practicality, feasibility, necessity, and real value of individually tailoring instruction for each learner must be understood by parents and the general public so that appropriate finances can be allocated through rational choice as opposed to ignorance.

According to Andersen (1983), the K-12 science curriculum projects of the 1960s, which were designed to accommodate many individual differences, should not be discarded when new programs are constructed but should be modified. These "alphabet curricula," have been demonstrated to adequately prepare more gifted or academically talented students for future science and engineering careers (Hufstedler and Langenberg, 1980). These programs failed because teachers couldn't or wouldn't teach science in a manner consistent with the curriculum philosophy of the 1960s programs (Hurd, 1969). Some vocal parents preferred the rhetoric of conclusions approach to which they were subjected as youngsters and which they forgot. Some students prefer memorizing to thinking, probably because they have not been provided with ample opportunity to practice thinking (Andersen, 1983).

We now have many modifications to these curricula and instructional approaches. We can identify learning difficulties earlier and diagnose remedies more precisely. We can facilitate thinking and problem-solving skill development through advances in theory and practice. The question that continues to confound curriculum renewal centers on the teacher, that is the ability and willingness of teachers to comprehend the literature and become motivated to begin to manage the diversity that exists in classrooms given appropriate support in terms of class size and special materials.

If we can assume that schooling (and education) should prepare learners who have the desire and ability to become actively involved in making decisions about science and technology-related social-environmental problems and issues, then emphasis of these skills proposed in new science curricula facilitate learning among each type of learner. The key is managing diversity in the curriculum to accommodate the variety of learning styles (Andersen, 1978). Get learners interested, keep them interested, and nothing will stop them from learning the significant science they need for life in a technological society. Interest is the point of departure (Tyler, 1949).

Teacher education programs must be designed to help teachers learn to manage diversity (Beer, 1975). This may require modification and perhaps lengthening of existing programs so that teachers can better cope with ever increasing demands of future curricula, parents, and the media. Certain areas of specific concern are evident in the literature and are summarized below.

Research has consistently shown that women and minorities do not achieve as well in high school science as do white males (Matyas, 1984). According to Kahle (1982), women and minorities are the disadvantaged majority if 'disadvantaged' is used in relation to the quality of training in science, including courses taken, experiences, achievement level, and attitudes. The gender gap increases with age. Females take fewer science courses in high school and university--especially physical science courses. Educational, sociocultural, and personal factors such as sex-role stereotyping, peer pressure, and lack of role models have been implicated in female science attrition (Kahle & Lakes, 1983). Factors affecting women and minorities are usually subtle and communicated by teachers and textbooks, often unintentionally and indirectly (Skolnick, Langbort, & Day, 1982). Evidence suggests that minorities are excluded from advanced science courses because they lack basic mathematical skills (Kahle, 1982). Teachers also appear to hold lower expectations for these groups of students (Hall, 1981).

In addition to raising teacher expectations, science curricula must be improved. Techniques such as individualized instruction have been found to be especially effective for minorities (Carter, 1982). For both minorities and girls, simple direct solutions such as increasing in-class and extracurricular science activities (more laboratory activities, field trips, home science activities) can be effective. Teachers can be more sensitive to inadvertent language errors, value judgments, and

assumptions so that they may be consciously avoided. Even at elementary levels, school authorities need to mandate more science for all so that selective disadvantages are less likely at advanced levels. School counselors must inform students about all options and restrictions as a result of course selection, and parents must foster positive attitudes toward science and technology as early as preschool years. Academic expectations must be equally high for all children--excellence must be encouraged and role models used for encouragement (Hall, 1981). Maintaining the widest variety of options is a goal applicable to all children, adolescents, and adults (Matyas, 1984). The Science Council of Canada (1984) study contains recommendations that are sensitive to the needs of women and minorities in science. These recommendations must receive attention as new science programs are developed.

Since the early 1970s, both the American Association for the Advancement of Science and the National Science Teachers Association have been actively addressing the issue of science education for handicapped youth (Redden, 1984). Surveys and studies have identified problems related to inadequate teacher preparation (in science and special education), inadequate materials, and lack of instruction and introduction to career opportunities or role models. However, some exemplary programs have been identified as models for change. Suggestions from these programs include mainstreaming as opposed to segregation, advanced teacher training in special education and science, conferences to share ideas and support organizations, and better access to new resources (see Hofman, 1984).

Much has recently been written to assist teachers in coping with the variety in learners in providing quality science programs and/or individualized adaptations. Some examples are included for consultation by curriculum workers.

Wolfinger (1984) provides a well-organized and apparently well-researched chapter on teaching children with special needs. She discusses seven groups of children with special learning needs: handicapped--visual, auditory, intellectual, or orthopedic; culturally different; gifted; and girls in science. Sections of the chapter discuss the role of science education, development and adaptations of teaching methods, activities, content, and verbal material for each group of students. The secret to success in science teaching is the provision of hands-on activities in an open inquiry or guided discovery method--within the mainstream where possible --but adjusting for language or experiential differences as well as ability differences.

For example, with respect to gifted children, Wolfinger (1984) suggests that inquiry permits a talented child to investigate phenomena at appropriate rates and levels without experiencing the stigma attached to "being ahead" of everyone else. Culturally different children, in activity-oriented science programs, have the opportunity to see and assess their effect on a system, and this can help these children to develop a sense of control that will carry over to other spheres of life (Rowe, 1973). Science in elementary grades can provide a child from a distinctly different

background with an experiential base that is similar to that of other children as well as vocabulary, problem-solving strategies, and exposure to variety in career choice. Elementary science can contribute to the development of abstract reasoning ability in gifted children--problem-solving applications to real life experience, to the development of research skills that allow pursuit of depth and breadth of topics commensurate with needs, and to the pursuit of careers in science. Enrichment (and reinforcement) are provided in many of the new elementary science programs.

Carin and Sund (1980) suggest many curriculum materials and practical ideas for individualizing science. Examples of ESS and Science 5/13 units and teacher adaptations are provided. Jacobson and Bergman (1980) provide in a section of their text suggestions for teaching science to children with a variety of handicaps (see also Abruscato, 1982; Awkerman & Teller, 1979; Davis & Rimm, 1985; Hoffman & Rickers, 1979; Katz & Bushnell, 1979; Knutsen, 1979; Kuhn, 1979; Pryt, 1979).

At middle and secondary school levels, Simpson and Anderson (1981) provide a useful chapter on science for exceptional students. They discuss a hierarchy of alternative learning environments from regular classroom experiences to hospitals (see also Molloy, 1976). They provide information on and implications for teachers of students with a wide range of learning and physical disabilities as well as mental and behavioral disorders. Examples of appropriate curriculum materials are also provided. The Biological Sciences Curriculum Study has developed three programs that have been successfully used with special students--Me Now, a program in science and health (ages 10-13); Me and My Environment, an environmental science program for mildly mentally handicapped (ages 13-16); and Me in the Future, a course dealing with careers and future decision making. (See also Dolmatz & Wong, 1976; Wong & Dolmatz, 1976, 1983a, 1983b.)

Simpson and Anderson (1981) discuss, in concise fashion, science education for gifted and talented students at intermediate and secondary levels. They cite research that advocates working with these students in regular classrooms and suggest some ways that teachers can individualize science learning experiences to meet student needs. Obviously, the teacher is a key factor in individualization for gifted and talented students who prefer science teachers with qualities like their own such as high intellect, flexibility, humane motives, sense of humor, curiosity, personal magnetism, sensitivity to others, widely varying interests, enthusiasm for self-improvement, excellent organization and so forth (Magary & Freehill, 1972). Brandwein et al., (1985) indicate that key figures in junior and senior high school, particularly the former, were significant influences in career choice for those gifted in science.

The Intermediate Science Curriculum Study (1970) is one example of an individualized self-paced, activity-centered set of instructional materials for intermediate grades (see also Simpson & Anderson, 1981, Chapter 8; Trienzenberg, 1972). This curriculum package illustrates how a core of learning activities can be

used as a basis from which remediation or enrichment can be optional branches. Some authors prefer the term personalized instruction (see Bybee, 1974), but whether the Keller plan (Keller & Sherman, 1974) learning activity packages, modules, audio-tutorials, computer directed instruction, or independent research, a common characteristic of all approaches to individualized instruction is self-pacing. Arguments for and against individualized forms of instruction are summarized by Marchese (1977). Advantages include provision of an environment for greater student participation and acceptance of responsibility; increased opportunity for students to evaluate their own progress; attainment of as much or more subject matter learning; and more positive attitudes toward self, school, and science.

Collette and Chiappetta (1984), in a chapter on individualizing science instruction in middle and secondary schools, discuss ways to motivate students to be independent learners within the widely accepted current emphasis on mainstreaming (see also Coble, Hounshell, & Adams, 1977). They conclude that a more individualized form of instruction is needed for a science in society approach and that this can be accomplished in group task settings where the focus is on individual responsibility.

Swanson and Denton (1977) report success with a mastery approach to individualization as do Yeany, Waugh, and Blalock (1979), although Lueckemeyer and Chiapetta (1981) suggest that considerable patience is required by teachers who are attempting to use alternative modes of instruction. The rewards are worth the effort and often result in improved strategies and materials for all students in science (Simpson & Anderson, 1981).

Relationship of Goals of Science Education to Goals of Education and Common Essential Learnings

Goals of education are generally grounded in the basic values of culture and society. Desirable individual or societal characteristics have tended to be reflected as valid concerns for the school. In North America, respect for the integrity of individuals, cultures, and society charges schools with fostering individual character development for responsible participation in society. Thus, goals for education and schooling center around development of basic skills that are intended to encourage the growth of personal and spiritual health and self-concept. These, in turn, provide prerequisites for the development of positive life styles, relationships with others, and effective membership in society. Basic skills are intended to develop into lifelong learning and problem-solving skills that equip individuals

for satisfying personal curiosity and making intelligent decisions in a constantly changing society.

Although it does not appear to be explicitly stated in the goals of education for Saskatchewan (Saskatchewan Education, 1984a), mention is made of intellectual development (p. 10). The implicit overarching goal of education is development of the ability to think. This is the assumption behind personal and social development. The development of ethical character and effective citizenship depends upon commitment to values, that is, the ability to reason sensitively and responsibly and to make choices based on understanding of the implications of alternative behaviors. This awareness demands the ability to think. The development of a set of common essential learnings (Saskatchewan Education, 1986) exemplifies this assumption.

Common essential learnings tend to elaborate on basic goal components of general education in that they list fundamental skills including communication; thinking and learning skills; personal and social attitudes and values; and cognitive abilities in areas of numerical, quantitative, and technological literacy. This current emphasis on a common curriculum or core is an attempt to move away from the hodgepodge of fragmented courses that characterized most school subject areas in the 1970s. It appears to be an attempt to bring some unity and educational equity to the provincial education system.

Science education as a maturing subject area has recently begun to define more precisely the dimensions of scientific literacy for the purpose of contributing to general goals of education--an opportunity which was overlooked in the past in favor of goals related to science content or the structure of the discipline. This change to a more outward-looking school subject--a science in society approach to science education--is favored by most science educators and should facilitate the task of relating experiences in science courses directly to general education goals (Johnson, 1983).

Scientific literacy, if acceptable as the overarching goal of science education, should considerably broaden the base of school science. Dimensions of science literacy include, in addition to understanding basic scientific knowledge, the application of science concepts and generalizations, and processes and skills for problem solving and decision making in areas where science interrelates with societal, environmental, and technological issues (Science Council of Canada, 1984). Current science teaching is not responding to the intellectual and knowledge demands of a society that has been transformed by advances in science and technology and by increasingly complex social and environmental problems of local, regional, and global dimensions. New social conditions raise questions about the purposes of education and what is worth knowing. An integrated system of science, technology, and society drives an economic system whose success depends on a general population that understands the interrelationships. People not so informed represent the new disadvantaged in society (Hurd, 1984).

The projected reform in science education aims to provide a more unified view of the nature sciences and their relation to student experience in the societal context. Personal and social-oriented objectives are to become as important in science classrooms as the narrowly focussed academic discipline goals now dominant in teachers' curriculum plans. Curriculum reform in science education should be guided by general educational purposes. Science education as a basic subject in the schools of Saskatchewan implies a core of essential learnings important for all students in developing perceptions of self, society, and the natural world; collective responsibilities to society; and an understanding of the universality of scientific concepts and generalizations.

A major goal in the reform of science education is to use knowledge and bring it to action. Quality in science classes will not be found in the amount of information that learners can recall, but in their ability to process and apply information in posing questions, analyzing issues, and making decisions. Students should be able to distinguish evidence from propaganda, probabilities from certainties, questions from pseudoquestions, rational beliefs from superstitions, science from quackery, data from assertions, science from myth and folklore, known from what is not known, credible from incredible, sense from nonsense, fact from fiction, and theory from dogma. These insights into the nature of information are critical, and they represent an aspect of student learning that is essential if we are to employ the subject matter of science courses to bring about rational thinking (Hurd, 1984).

The tone of the new goals of education in Saskatchewan is more personal and attempts to characterize an educated person. Reform in science education is attempting to sort out, from all that is known about science and technology, subject matter that is most likely to be important in the personal and social affairs of people as citizens in a democracy. Thus, knowledge confined to one discipline at a time is insufficient in scope for examining intelligently science-related personal, social, and environmental problems. Basic principles and processes are background validity checks on knowledge and are essential. However, to be meaningful and useful, operationalization of this knowledge is also necessary. Knowledge is a state of understanding that transcends the learning of isolated facts and definitions. One of the most important objectives of science is to enable students to use what they learn to acquire even more information--to become independent learners. This implies interpretation and application of what has been learned, and this requires students to understand information at the concept and generalization level. The factual level has insufficient potential for critical thinking and application.

The ability to process and use information depends not only on knowledge but on cognitive abilities such as reasoning, problem solving, and decision making. These thinking processes depend upon knowing how to analyse, synthesize, and interpret knowledge and these skills, in turn, depend upon more basic processes such as observing, comparing, classifying, measuring, describing, experimenting,

making reasonable guesses or hypothesizing, inferring, recognizing variables, isolating problems, making judgments and interpretations, locating valid sources of information, extrapolating, identifying and evaluating experts, and questioning (see Wolfinger, 1984). How attributes of thinking, problem solving, and decision making are combined and applied depends on the nature of the problem and available information. Thinking and associated process skills cannot be learned in isolation but require development by working on an array of problems in the context of science, technology, environment, society, and human values (Hurd, 1984).

The current reform in science education focusses on the science needed by citizens for personal and social decision making. Every day people are faced with choices that require a knowledge of science--whether to avoid junk foods, purchase megavitamins, or contribute to cancer research. The educational goals related to self-concept and responsible citizenship are involved when students in science are taught how to access, organize, and analyze information leading to responsible choices in science-related social issues. In the real world, decisions involve more than analyzing information. Solving problems, whether personal, social, or environmental, involves values in considerations such as degree of risk, uncertainty, cost or benefit, trade offs, alternatives, appropriateness, acceptability, connections to other problems, and ethics. What criteria are used to reach decisions--ethical, economic, aesthetic, humanistic? The teacher's responsibility is to deal with value issues not by instilling a particular set of values in students but by encouraging debate on alternative value positions using rational processes and information.

As one of the subject areas that contributes to general education, science represents one way of looking at the world. A perspective of science contributes to the development of basic skills through development of the processes or thinking skills and acquisition of concepts and generalizations of science. Ability to examine problems and make responsible decisions, as a goal of scientific literacy, is based on use of basic process skills in complex ways that contribute to personal competence in the development of self-concept, positive life style, learning how to learn, social competence in the development of interpersonal communication skills, and active participation in societal decisions.

With respect to personal-social competence, science provides a kind of world view or philosophy based on knowledge about scientists and science, its aims, its epistemology (character, structure, and limitations of the knowledge system), its strategies, its values, its functions, its interaction with society and environment, and its human characteristics and needs (see Aikenhead, 1980; Aikenhead & Fleming, 1985). Science has traditionally provided students with a firm knowledge foundation. Reform in science education intends that more attention be focussed on other equally important goals relating to process; attitude; relationships to other areas of study; and the world of science, technology, society, and environment. This involves consideration of the nature of scientific knowledge and thus the concepts of change and rate of change; application of science concepts and generalizations to society and environment; use of science processes in solving

problems, making decisions and developing lifelong learning tactics; characterizing decisions on underlying values of science such as constant inquiry and questioning, demand for verification, respect for logic, and consideration of premises and consequences; appreciating the interrelatedness of science in society and environment; and a desire to pursue study of science-related issues.

Given the science and technology-driven society envisioned by the year 2000 (Saskatchewan Education, 1985b), knowledge and processes that facilitate thinking and decision making concerning science-related social and environmental issues are the basic ingredients for personal and social competence, that is, positive self-perception and responsible citizenship.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are based on a review and analysis of the literature in science education; some thoughts and informed viewpoints of science educators representing all levels of the educational spectrum; and examination of related literature in areas such as curriculum theory, evaluation, special education, environmental education, and policy development. The framework for the literature search was established by a set of guidelines from Saskatchewan Education. Major international databases and all Canadian education databases were accessed using criteria determined by the framework. Synthesis of research findings, not personal bias, resulted in these conclusions and recommendations.

Obviously, considerable weight was given to major detailed studies of science education in Canada by the Science Council of Canada (1984) and by Connelly et al. (1985). These studies, characterized by Connelly et al. (1985) as entrepreneurial crisis research, involved contract research with short-time deadlines and built-in accountability. The present document has also drawn heavily on major studies of science education in Great Britain (Association for Science Education, 1981) and the United States (Harms, 1981).

Given the short time allowed for literature analysis, this policy report made use of a large number of secondary syntheses and meta-analyses of the science education literature. Although many of the original sources were examined, it remains necessary to assume that the secondary representations and conclusions of original thought and research are valid and reliable. The conclusions and recommendations are organized so that they parallel the categories used to suggest strategies for implementation by the Science Council of Canada (1984).

Curriculum Resources

1. **Science learning experiences should be provided to all children, for at least the minimum prescribed time per week, throughout the period of compulsory schooling.**

   Although this policy already exists in Saskatchewan, there appears to be no accountability for its implementation. Children in elementary school receive only a token education, if any, in science. At middle and secondary levels, science tends to be narrowly based on textbooks that do not focus on all of the goals that existing curriculum documents list for science education. A more authentic view of science must be presented--one that emphasizes a science-technology-society-environment connection; adds a Canadian context; accounts for individual differences and special needs among all students; is relevant to the real world lives and interests of students; and facilitates a reasonable balance among all of the goal areas of scientific, technological, and environmental literacy. Simply stating goals is not enough. Curriculum committees must develop mechanisms to ensure that teachers emphasize balance among goals relating to personal and social needs as well as the only goal seriously addressed by teachers at present--academic preparation.

2. **Science education from kindergarten to twelfth grade must form a comprehensive, coherent, and consistent learning framework that clearly contributes to the goals of education and common essential learnings for Saskatchewan.**

   Existing science curriculum committees tend to be responsible for K-6, middle years or intermediate science, or senior subject disciplines. No overarching steering committee exists. The development of a K-12 framework for science education in Saskatchewan requires that such a committee be established by Saskatchewan Education. It would seem logical that the terms of reference for this committee should include policy generation, revision, and evaluation; monitoring the work of division level science curriculum committees; and liaison with other subject areas and general core education committees that are assessing progress toward common essential learnings. At this level, curriculum decision makers would attempt to articulate and reach consensus on conflicting conceptions of curriculum and of science education. An early product of this committee would be a Science Framework (K-12) for Saskatchewan.

3. **Science curricula at all levels of education should provide a science-technology-society-environment emphasis.**

   Science is either nonexistent or boring and irrelevant to the vast majority of students in school today. Many students hate science. Many elementary

science teachers prefer not to teach it. Many middle and secondary teachers kill enthusiasm for the subject by the lecture/textbook methods of presentation that focus narrowly on content and structure of the discipline. Despite a progressive new Division III curriculum guide that advocates wide-ranging goals and some innovative methods, teachers complain about the textbook chosen by their school. Students forget almost all of the content learned and turn away from careers in science and technology-related fields. Teachers insist that they must prepare students for the next higher level whereas teachers at higher levels assume very little in terms of prerequisite knowledge and skills. This represents a crisis in science education.

A major reform movement is underway in science education. This movement forcefully advocates a science in society approach to science education and bases the rationale for change on results of research from many countries. The reformers do not advocate a watering down of existing science curricula. However, some current detailed content is thought to be unnecessary for intelligent voting citizens, although it may be appropriate for a small number of gifted and talented students who wish to pursue science at university or technical school. This specialist option should remain for a minority. Mainstream science, however, must change. Basic concepts and generalizations must be taught in more interesting and relevant ways that reemphasize process learning advocated in the 1960s but go beyond the disciplinary boundaries of science to its application in problem solving and decision making in science and technology-related societal and environmental problems. This movement is widespread and powerful. It is not a passing fad or band wagon. It must be reckoned with--now.

4. (a) **The elementary science curriculum must be developed so that a reasonable core of science material will be presented to all children daily by teachers who have not specialized in science teaching. A rich array of supplementary materials should accompany the basic core in order to provide for individual differences among students and teachers.**

Very little science is taught or taught well in the elementary schools of Saskatchewan. The elementary science curriculum was last revised in 1971. This curriculum was primarily centered around broad conceptual schemes, although process was emphasized through an almost totally activity-oriented approach to science. Teachers did not and do not use this curriculum. They indicate that this curriculum assumes too much in terms of teacher science background, preparation time, student ability, and evaluation.

Given the reality of the characteristics of teachers and classrooms and assuming that curricular revision in Saskatchewan will hold all teachers accountable for exposing children in all classes to regular high-quality

science experiences, what can be done to maximize the probability that science, hopefully high-quality science, will be taught for a minimum of 160 minutes per week? The Science Council of Canada recommends 45 minutes per day or 15% of school time.

Teachers require the assistance of a science curriculum that they can and will use. Curriculum committees have choices depending upon resources. Curricula can be invented, adapted, adopted, or can include various combinations of commercially prepared materials and locally designed supplements. There are many legitimate criticisms directed at textbook curricula. However, the most recent commercial curricula (since 1980) have responded to teacher suggestions and provide a basic science program (K-6) that would be difficult to surpass without costly development. Although science purists may consider these curricula as lowest common denominators, overly standardized, or insufficiently Canadian or regional, they appear to provide sound basic science experiences that include most of the characteristics that educators demand. Given a basic packaged program, valuable provincial resources could be used to adapt it to Saskatchewan and supplement it as needed. Personal research indicates that teachers who do not teach science, once given appropriate inservice, can and want to teach using these materials.

Several possibilities exist for curriculum committees to consider. One option would be to select one commercial program (post-1979) and then allocate provincial funds for improving teacher training programs, increasing department personnel, and providing high-quality inservice for teachers. A reasonable corollary would be to recommend three or four options that would then involve school district teachers in the selection process (similar to the development model used in British Columbia). This approach would be reasonable and logical because of the similarities among these most recently developed programs.

The second option would be considered an extension of the first. After selection of a curriculum, a curriculum guide would be developed that prescribes core and optional units and generally provides teachers with a road map that has a unique flavor. Examples of this form of curriculum adaptation are readily available. For example, developers could examine the science handbooks prepared in Ontario by the Science Teachers Association and Queen's University, or the Alberta elementary science curriculum guide. It is noteworthy that a great deal of effort resulted in a supplementary guide to the materials-based program (one of three recommended alternatives in British Columbia). This guide was largely disregarded by teachers who focussed on commercially prepared teachers' guides.

The third option would involve curriculum committee selection of appropriate units from a large number of commercial and noncommercial sources--units the committee could tailor to unique Saskatchewan and Canadian requirements. The SEEDS curriculum (Society, Environment & Energy Development Studies Foundation, 1981-83) developed in Alberta, which has excellent regional materials, could form the basis of organization. Particular concepts that may not be developed by the SEEDS curriculum could be developed as supplements.

The fourth option would involve selection of activities that exist in other resources. Units would be pieced together and organized into yearly programs.

Additional options are also possible as extensions or combinations of those presented above. For example, British Columbia provides teachers (actually individual schools) with choices of three options that are intended to account for a range of teacher strengths and weaknesses. Obviously, it will be impossible to satisfy the unique needs of every teacher or observer. However, the task of the curriculum committee would be to maximize science teaching probability given available resources. It is encouraging that many elementary teachers who do not presently teach science state that they would be willing to do so if appropriate materials and support services (such as inservice) were available.

Connelly et al. (1985) recommend that if research is required to substantiate claims such as those made above, then it is more appropriate to provide a needs assessment rather than a learning assessment. Why? Because the results of their comprehensive study of science education in Canada were largely confirmations of intuition.

A second note--if science educators base their assessment of commercial curricula on pre-1980 editions of these materials, then reassessment of new editions that include teacher evaluations (criteria for such examinations may be found in sources such as Cain and Evans [1984]) is required. For example, the evaluation of the 1975 edition of STEM Science, published by Addison-Wesley, is unfavorable in almost every criterion studied compared with the 1980 or 1984 editions of Addison-Wesley Science.

Teachers must use the suggestions provided by these new materials and devise strategies to provide for individual differences among students. Females must be encouraged, cultural diversity must be accounted for, learning and physical disabilities must be compensated for, and gifted and talented students must be challenged.

The process revolution in science teaching was not a passing fad or a temporary emphasis, nor was inquiry teaching. In the current reform movement, science teachers are encouraged to retrain or accept inservice to better understand how to use these methods. The added requirement for the 1980s is to develop and maintain student interest and to extend their abilities through a science-technology-society-environment approach that develops problem-solving skills and demands that personal values and attitudes be confronted in science-related decisions that have environmental and societal relevancy.

(b) **The science curriculum at middle years should be designed so that the taught curriculum accommodates the particular needs, interests, and abilities of early adolescents. Students should be provided daily opportunities at direct, hands-on learning experiences in field and laboratory. Current emphasis on content, which is viewed by students as boring and irrelevant, is unsatisfactory.**

Science at the middle or intermediate level in Saskatchewan is primarily textbook science. The Division III science curriculum, revised in 1979, is a progressive document that lists wide-ranging goals, suggests a multi-textbook approach to science, and provides many activities and resource suggestions beyond the recommended texts. Schools were allowed to select a textbook and teachers were encouraged to make use of many other texts as references. In theory, teachers were given considerable freedom to provide quality science experiences within the traditional life, earth, physical science framework. In practice, science at this level tends to be centered around one textbook which many teachers do not believe meets their needs. If only the right textbook could be found! This gap between intended and taught curricula appears to be a severe problem in science according to the report of the Science Council of Canada (1984). Science begins to take on the undesirable characteristics of secondary science at a stage of preadolescence when students require appropriate motivation from active involvement, not passive reception. New large-scale research results indicate that the middle school period is crucial in development of student attitudes to science and future occupations (S.M. Haggerty, personal communication, March 20, 1986).

New courses in life science (Grade 7), earth/ecological science (Grade 8), and physical/chemical science (Grade 9) should be designed to develop basic science concepts and generalizations through experience in use of basic science process skills within a science-technology-society-environment context. Learning experiences should be activity centered and focus directly on development of major processes, concepts, and attitudes identified in the scientific literacy goals. Learning experiences should emphasize applications of basic science concepts and skills to students' personal life situations. Students should begin to examine

science-related societal issues through simulations and real-life experiences. Application through activity is necessary during middle years to ensure that learning occurs.

Assuming that students under the Saskatchewan core curriculum will have experienced appropriate early development of basic science concepts and process skills, the middle years /intermediate science curriculum committee should design or adopt materials to build on the K-6 experience. This committee will have options similar to the elementary committee with respect to curriculum design. Excellent science in society materials exist and are being developed. These materials should be examined carefully and appropriate sections, units, or activities adopted within the chosen framework design. Serious consideration must be given by this committee to the question of "textbook withdrawal" by teachers. Withdrawal is a painful process. However, given the virtually worldwide student reaction to current science curricula at this level and the crisis it has generated within the discipline, change is essential.

Given the background and experience of teachers in middle school science, content is not the problem--instruction is the problem. Inservice at this level should focus on expanding the teachers' repertoire of instruction techniques and enhancing teachers' ability to construct productive and creative learning environments.

(c) **A balanced core of two years of secondary science should be the minimum required of all students, consisting of one year of life science and one year of physical science--both taught in a science-technological-society-environment context. These newly designed courses should provide students with opportunities to develop skills in identifying science-based societal and environmental problems and in making decisions about their resolution. Many good models for courses like this have been developed. Preparatory to science-technology-society courses, a course such as Science: A Way of Knowing could be optional at the tenth grade level** (see Aikenhead & Fleming, 1985).

Students interested in exploring or preparing for careers in science, engineering, or technical fields should have the opportunity to take discipline-based courses in advanced biology, chemistry, physics, and geology. It is anticipated that this group would be much smaller than those who currently take biology, chemistry, and/or physics, and some individualized learning experiences might be arranged for students in smaller rural schools.

All courses in high school science would receive equal university and technical school credit. New courses would not be "watered down" science courses but rather science courses with a new emphasis. They

would be designed to help students cope individually with an increasingly technological world and to participate intelligently in decisions requiring knowledge of science and technology and their effect on society and environment. In Saskatchewan, these new courses could incorporate information that currently exists in agriculture courses. The focus, however, would be on applying information for problem solving.

Recent surveys of Saskatchewan secondary school teachers indicate that they are generally satisfied (80%) with the kind and quality of science experiences that they provide for students. However, students indicate that they do not enjoy (many hate) their high school experiences in science. This trend is found in Saskatchewan and elsewhere in Canada (Science Council of Canada, 1984).

Science in high schools is taught from textbooks primarily through a lecture format. Students describe it as boring, irrelevant, and the reason that they turn away from careers in science and technology. Students in Saskatchewan must take one science course at this level. Beyond tenth grade science, which is compulsory, discipline-bound courses in biology, chemistry, and physics are the most common available courses (agriculture and geology are available but not popular) and are viewed by teachers as courses intended to prepare students for university-level science (an inappropriate assumption in the minds of many university science professors). The texts used are typically original or revised editions of the structure of the discipline courses designed for the university-bound students of the early 1960s. Other texts used for biology are content-based versions that were popular in the 1940s and 1950s. Facts are emphasized over concepts and generalizations. In theory, science programs of the 1960s were textbook-centered, but excellent resources were designed to complement and enrich the program. In practice, the textbook is the course, and the evidence for this is found in the curriculum guides for the three disciplines. This kind of curriculum development, the kind of teaching seen in many high school classrooms, and the lack of accountability required by school boards is not only inadequate, it is irresponsible to the parents and children of Saskatchewan. It should be noted that the developer of PSSC physics, in testimony before a committee of the United States congress, stated that these science curriculum projects were designed for the scientifically gifted university-bound students because they (curriculum developers at that time) could not do everything at once. Less than 5% of high school students major in science at universities.

Secondary science teachers admit that the greatest problem with respect to resolving this severe crisis in secondary science is other secondary science teachers. As the Science Council of Canada (1984) notes, a science-technology-society emphasis, not a structure of the disciplines

approach, is more appropriate for general education of the majority of high school students. Change must occur and this will be difficult given the predisposition of secondary science teachers to teach as they were taught by their university professors (see Medvitz & Watson, 1979).

Secondary school science is not merely a screen for postsecondary institutions. The primary responsibility in secondary science is for general education. Whether in traditional academic courses or alternatives, topics should be presented within personal, societal, and environmental contexts. The effect of human activities and technology on the world as well as our dependence on that world and our responsibility for preserving it, should be emphasized. Much more emphasis should be placed on humans than currently exists. Course work out of the classroom that focusses on urban, rural, and natural settings familiar to students should be emphasized as well as classroom investigative research that is local, regional, or global in scope and focus.

The discipline-based courses in biology, chemistry, physics, and geology should be redesigned to be more appropriate to the needs of students who will enter science careers or become adult citizens in a world with twenty-first century technology. Even students who intend careers in science or science-related fields require courses that balance all of the scientific literacy goals. Currently the goal for these courses is narrowly focussed around text-oriented, lectured input and rote recall output which is boring, repulsive, and irrelevent to students. Students learn to hate science as a result of these experiences. Secondary sciences must be rethought and retaught to be more responsible to the entire range of goals and objectives. This means that course material must include topics and learning activities related to personal, societal, and career emphases on an equal basis with knowledge acquisition. More detail is provided in the scope and sequence document.

In addition, a better balance must be achieved between already stated curriculum goals related to concepts, generalizations, and process skills. The large curriculum projects of the 1960s advocated a shift toward these goals from sterile presentation of content and this was sometimes ignored or intentionally subverted by teachers intent on lecturing content from their university course notes. The lessons learned from attempts at curricular change in the 1960s included devising better mechanisms for teacher inservice to assist them with required changes followed by monitoring in classrooms to insure that balance is achieved among goals agreed upon for students' science learning.

Basic science knowledge is required by students who plan to enter science-related careers as well as by citizens who are responsible for making science-related societal and environmental decisions. However,

in order for students to be able to apply their knowledge of science to personal, societal, and environmental problems, it is necessary that they understand these problems or aspects of science that apply to these problems as well as ways of accessing, processing, analyzing, and evaluating conflicting information about science-related social issues so that intelligent decisions can be made.

Science courses designed to produce student outcomes such as these should logically be designed to present science in context, in contrast to an abstract representation divorced from student reality. In this case, active participation should be as much a part of secondary science programs as it is in new elementary science programs. However, the emphasis, in addition to the familiar laboratory science, would be investigative problem solving. Active participation in this sense would include identification and definition of problems to be attacked or decisions to be made; application of the processes of scientific inquiry in acquiring, interpreting, and using information; and practicing skills of decision making in problem resolution. A variety of problems relevant to personal, societal, and environmental issues should be included and a variety of processes for problem resolution and decision making would be examined in integrated fashion with social studies and other subject areas such as aesthetics, home economics, and industrial arts.

Obviously, decision making involves inclusion of individual values and preferences on a base of knowledge. Decision-making or values-clarification learning activities that ignore science knowledge, research data, or potential technological developments are pointless exercises in opinion swapping leading to a pseudosophistication in science-related issues, which is probably worse than the pooled ignorance and functional incompetence that currently exists among students and adults in society.

The fact remains--simple acquisition of information is not in itself adequate for the pursuit of any of the important goals of scientific literacy and personal-social competence. Scientific concepts and generalizations are needed in the interpretation, analysis, and resolution of issues. New course materials are also needed in developing future problem solvers and decision makers. The assumption of transfer from information acquisition to ability to make decisions is not enough; experience and practice are required. This is the reason for all of the rhetoric in science education today.

Curriculum Leadership

5. **Changes in education are often agreed to in principle, even stated in government policy, but fail to become established in practice. To maximize the probability of effective change in schools, teachers must receive the support of curriculum leaders in education at all levels of decision making.**

   (a) **Saskatchewan Education should designate a position of provincial science coordinator in the curriculum branch.** The highly qualified individual selected for this position, a science education curriculum specialist, would be responsible for curriculum development, implementation, and assessment of science and would be responsible for no other curriculum area. The individual should have research capabilities, conduct long and short-term reviews, large-scale and small-scale assessments, encourage diversity in local curriculum development and implementation, and be enabled to communicate and meet regularly with counterparts in other provinces and countries. The provincial coordinator would oversee advisory and curriculum committees, act as a consultant to school districts, organize provincial inservice efforts, and perform other designated duties as required. Ideally, the department should have elementary and middle/secondary science consultants to assist with these duties, but if this is not possible, the coordinator should have experience with elementary and secondary program development.

   (b) **Saskatchewan Education should establish a provincial advisory council for science education.** Members of this council, whose meetings would be organized by the provincial coordinator and financed by the department, would consist of science consultants from each school district, university and technical school science educators, and scientists and others interested in science education policy matters (parents, students, teachers, and appropriate Saskatchewan Teachers' Federation, Saskatchewan School Trustees Association and business and labor representatives). Twice yearly meetings would be organized to discuss progress, problems, and new initiatives. District members (consultants) would submit annual reports on district science progress.

   (c) **Saskatchewan Education should establish curriculum committees for each of elementary, middle, and secondary sciences.** These committees would be working committees, with new terms of reference, that consist of six to eight selected applicants each. Preference would be given to individuals with interest and/or experience in curriculum work--highly motivated and committed to excellence, but open to innovation and change as a research quest. These groups, under the provincial coordinator's direction, should devote a minimum of 20 days of the school year (10 days autumn term, 10 days spring term) at depart-

ment/district shared expense, to intensive curriculum writing sessions--primarily to localize, supplement, and/or change science programs for a wide variety of purposes including enrichment, reinforcement, special field experiences, audio-visual (videotape, videodisc) development, resource and library supplements, literature reviews, research and publication, and so forth. On-going active curriculum work is required to help teachers maintain currency in science and in educational matters.

6. Saskatchewan Education, through coordinator and consultants, should require that the following conditions are insured for Saskatchewan school students and the public:

   (a) **Science should make up at least 15% (45 minutes per day, on average) of the curriculum, K-6, and all students take a science course every year through grade 11 as a condition of high school graduation.**

   (b) **Science should be taught, at all levels, so that the complete range of goal statements are equally pursued and demonstrated in evaluations and assessments or research studies.**

   (c) **Science courses should accurately reflect the nature of science and scientific activity in local, Canadian, and global contexts through a science-technology-society-environment emphasis.** Elementary science should focus on nature and urban study of the child's environment as the basic process/concept curriculum is adapted to local settings. Middle years experiences in life, earth/ecology, and physical/chemical science should develop science knowledge and skills within a societal framework that motivates interest and stimulates investigation of real problems. Secondary science should develop problem-solving and decision-making skills in science-related social and environmental issues through biological and physical science-technology-society-environment courses or through more specialized advanced studies in biology, chemistry, or physics.

   At all levels, this science emphasis should influence curriculum development and selection of course methods and materials, including textbooks.

   (d) **Student achievement in science, at all levels, should include evaluation of the full range of science goals and objectives.** This can be facilitated by department-initiated activities to develop evaluation materials that test more than academic content.

   (e) **Science program implementation and evaluation should be monitored through assessment which may entail large or small-scale sampling research.** Whatever means are chosen to evaluate programs, department

responsibility should require that science teachers be accountable for science experiences provided to Saskatchewan children. Monitoring should be required by district personnel. The full range of ability levels, learning styles, cultural differences and these topics should be reported on and discussed regularly by curriculum and advisory committees at meetings organized by the provincial science coordinator.

7. **School divisions, assuming provincial authority and resources, should appoint a district science consultant to provide information and support to teachers and to school science programs.** The Science Council of Canada (1984) report describes this specialist resource as essential for improved science programs. In small school divisions, this individual might have additional subject area responsibilities. The division consultant should be trained in science and education curriculum development, adequately supported through professional development, and enabled to meet regularly with corresponding individuals in other school divisions. Saskatchewan Education should facilitate such meetings twice yearly. Consultants should work with the provincial coordinator to organize inservice experiences that follow teachers into classroom implementation. Initially, this would be a major responsibility of consultants. These individuals should have opportunities to attend and report on national and international science conferences.

8. A critical requirement in developing and maintaining high-quality science experiences is school-level leadership. The Science Council of Canada (1984) reported a lack of leadership and coordination of science at the school level. Teachers are isolated behind closed classroom doors with little opportunity to observe colleagues and are not given time to put their experience to work in curriculum renewal.

   (a) **Principals should initiate and support, in terms of school time and resources, school-based discussions about science teaching development, curriculum implementation, and local adaptation possibilities.** This requires organization and regularly scheduled deliberations.

   (b) **Principals should insure that it is possible, convenient, appropriate, and even necessary for teachers to observe their colleagues' teaching, to develop skills of analyzing teaching, and to experiment with innovative methods in the spirit of research (i.e., every innovation may not "succeed" but the teacher may learn from the experience).**

   (c) **Principals should work to develop the school climate so that a non-threatening environment exists providing open and private means for coping with the dilemmas of teaching.** Models of reflective and self-analytical teaching are available.

Human Resources

9. Given the implications of the report of the Core Curriculum Advisory Committee (Saskatchewan Education, 1986) that mandates science and the report of the Science Council of Canada (1984) that advocates substantive change in science curriculum and instruction, some strategies are required to link the processes of curriculum implementation to those of teacher growth and development. Given the low numbers of new teachers entering school systems, inservice education is at least as important as preservice education in promoting reform in science education. Science teachers, as professionals, are responsible for their own growth and development. However, support is useful and necessary when the profession does not require the full-scale retraining that other professions do require.

   (a) **Science teachers should develop annually, in consultation with elementary consultants (or principals) or secondary consultants or department heads, a three-year professional development plan setting out personal goals and development needs (in relation to the school science program) and strategies for meeting these needs** (Science Council of Canada, 1984).

   (b) **Science teachers should use a minimum of 15 days annually for professional development activities, five of which may be during the regular school year.**

   (c) **Science teachers with particular knowledge or expertise, for example, in science in society methods, should be encouraged to lead inservice and school-based staff development activities.**

10. **Teaching certificates should specify subjects or levels that the holder is qualified to teach.** This means that the provincial department of education must work with universities to reexamine minimum standards and qualifications. Although it is recognized that some unprepared teachers are assigned to teach science classes, school boards should accept responsibility for providing those teachers with appropriate training to meet acceptable standards.

11. Education faculties encounter students, particularly those intending to teach at secondary levels, who have already accumulated a body of knowledge and developed attitudes to teaching, education, and the profession. As students of undergraduate and usually not graduate science programs, they adopt for use in their classrooms models of university science teaching for adults that are not appropriate for children or adolescents. They tend to have a narrow view of science as content from textbooks and lectures. This is reinforced by inadequate role models among existing teachers who then attempt to enculturate the novice into the existing prestige and reward system. Many faculties

of education must continually work to add breadth and variety to instructional repertoires. More cooperation among all university departments that contribute to the education of professional science teachers (i.e., education, arts, science, and engineering--which will have a greater future role) is required.

(a) **University departments that contribute to teacher training must cooperate to provide the policies, programs, and courses that aspiring teachers need to educate children in science.** Courses in biological and physical sciences should be a requirement for all teachers if science is part of the core curriculum. Teachers also require understanding of the social and human foundations of science and education in society to provide the background to effective science learning experiences.

(b) **University interdepartmental communication should encourage highly qualified students with appropriate personality characteristics and dispositions to consider science education careers.**

(c) **University education faculties should prepare science teachers to use a variety of alternative teaching strategies and techniques so that the full variety of goals of science education can be achieved.** Sterility of science classrooms and the resulting student distaste for science must be changed and the needs of all students must be met.

(d) **Universities, the department, and school boards should cooperate to develop and test models of continuous teacher education where science teachers are required, through inservice and training and motivated by a career ladder, to participate in continual development (i.e., special science summer institutes).**

Instructional Resources

12. Good quality science teaching requires facilities, equipment, and flexible scheduling for urban, rural, and natural environment field experiences.

    (a) **Elementary classrooms should be equipped with running water, a number of electrical outlets, and have access to certain basic curriculum resources (hardware i.e., microscopes, consummables, kits) that are easily obtained, used, and stored.**

    (b) **Elementary schools should have adequate space and shelving assigned to science storage. One teacher could be assigned the responsibility for equipment organization, maintenance, distribution, and replacement.**

Division board resource centers could maintain and circulate expensive specialized equipment and science kits.

(c) **School districts and principals should insure that provisions are made for equipment, that teachers are given assistance as needed, and that safety requirements are satisfied. Provisions might include library or resource center books and materials, for example, a variety of curriculum programs and supplementary materials.**

(d) **Middle and high schools should have a wide variety of teacher and student resources including science teacher education periodicals, and they should document circulation of these resource materials.**

(e) **Middle and high school science teachers should receive administrative cooperation in creating time blocks that accommodate longer periods for science field and laboratory experiences and investigations (including half day and full day blocks).**

13. **Students should be exposed to science that is more than textbooks, lectures, and laboratory manuals that develop only the lowest level scientific skills.** Curriculum guidelines in science specify objectives related to critical thinking, creativity, and problem resolution. Textbook publishers attempt to provide what will sell and hence have little incentive to be innovative. This means that teachers must be competent in science and also educational practice--especially alternative instructional strategies.

External Resources

14. Science education in Saskatchewan is enhanced through conferences, publications, and activities of the Saskatchewan Science Teachers Society (SSTS) and the Saskatchewan Outdoor and Environmental Education Association (SOEEA).

(a) **Science teacher organizations should become more active in recommending, to the department and other government and nongovernment agencies and organizations, ways in which science education can be improved. These groups should also adopt strategies that insure that the public understands their messages and that teachers have opportunities to debate the issues.**

(b) **It is to the benefit of the department, school divisions, teachers, and subsequently the public that science education organizations such as the SSTS and SOEEA be assured of funding to alleviate this most irritat-**

ing problem of activist organizations and to facilitate their programs, publications, and public conferences.

(c) **Teachers should insure that they are aware of a wide range of potential community resources for use in and out of school to enhance their science programs. Department, division, and science teacher association publications and materials can facilitate this.**

Research Resources

15. (a) **The SOEEA and SSTS should be given provincial assistance to conduct small-scale research projects of interest to individuals or groups and relevant to Canadian and Saskatchewan science education.**

(b) **The Canadian Association for Science Education, in cooperation with SSTS and SOEEA, should work to develop a program to identify and describe examples of excellence in Saskatchewan science education.**

CONCLUSION

Science education and the provision for science education in the province of Saskatchewan must change. Change is a painful process. New directions are easy to criticize. After all, they have not been tested whereas traditional ideas have ample evidence of success. However, conventional modes of operation have failed Saskatchewan students. Perhaps those students intending to pursue science careers at university or technical schools have been served to a degree. This is debatable. The vast majority of students who will become voting members of a citizenry capable of assessing government policy are functionally illiterate in a society so governed by economics and scientific technology that new and different skills are required. These are the implications of the report of the Core Curriculum Advisory Committee. These are the implications for one of its key recommended core subject areas.

One must be optimistic that the public has the vision and that teachers have the drive and determination to improve the quality of science education in Saskatchewan schools. When the culture and social system advance, the education system must advance. We face unprecedented social and environmental problems of local, regional, and global dimensions. Citizens of a twenty-first century democracy must be able to think intelligently about science and use science skills and knowledge to make informed decisions on science-related social issues. They

are inadequately prepared to do this at present. The assumption of transfer of scientific facts to understanding how to make societal decisions has proven to be inadequate. To not change is irresponsible.

BIBLIOGRAPHY

Abimbola, I.O. (1983). The relevance of the "new" philosophy of science for the science curriculum. School Science and Mathematics, 83(3), 181-193.

Abraham, M.R., & Fox, F.W. (Eds). (1979). Science education/society: A guide to interaction and influence (1979 AETS Yearbook). Columbus, OH: Ohio State University, ERIC-SMEAC.

Abruscato, J. (1982). Teaching children science. Englewood Cliffs, NJ: Prentice-Hall.

Aikenhead, G.S. (1980). Science in social issues: Implications for teaching. Ottawa: Science Council of Canada.

Aikenhead, G.S. (1985a). Collective social decision-making: Implications for teaching science. Bulletin of Science, Technology & Society, 5(2), 117-129.

Aikenhead, G.S. (1985b, October). School science for social responsibility: A proposal for positive action in secondary schools. Paper presented to Directions: A Canadian Conference on Curriculum, Instruction, and Leadership, Saskatoon, SK.

Aikenhead, G.S. (1986). Does school science reflect real science? Accelerator (Newsletter for the Saskatchewan Science Teachers Society), 12(2), 7-11.

Aikenhead, G.S., & Fleming, R.W. (1985). Science: A way of knowing (3rd ed.). Saskatoon, SK: University of Saskatchewan, Department of Curriculum Studies.

Aldridge, B.G., & Johnston, K.L. (1984). National science teachers association: A response to the national reports. NASSP Bulletin, 68(470), 20-24.

Allen, R.F., LaHart, D.E., Dawson, G., & Patterson, M.D. (1976). Toward goals for multidisciplinary energy education. Journal of Environmental Education, 8(4), 8-17.

Almy, M. (1966). Young children's thinking: Studies of some aspects of Piaget's theory. New York: Columbia University, Teacher's College Press.

American Association for the Advancement of Science/National Association of State Directors of Teachers Education and Certification. (1971). Guidelines for preparation programs of teachers of elementary and secondary science. Washington, DC: AAAS/NASDTEC.

American Forest Institute. (1977). Project learning tree. Washington, DC: American Forest Institute, Inc.

Andersen, H.O. (1978). The holistic approach to science education. The Science Teacher, 45(1), 27-28.

Andersen, H.O. (1983). Do we tap the individual uniqueness of students in school science? In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Anderson, R.D. (1981). Physical science education. In N.C. Harms & R.E. Yager (Eds.), What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Anderson, R.D. (1983a). A consolidation and appraisal of science meta-analyses. Journal of Research in Science Teaching, 20(5), 497-509.

Anderson, R.D. (1983b). Are yesterday's goals adequate for tomorrow? Science Education, 67(2), 171-176.

Anderson, R.D. (1983c). Science: Its period of neglect must end. NASSP Bulletin, 67(464), 63-67.

Applebee, A.N. (1981). Writing in the secondary school. Urbana, IL: National Council of Teachers of English.

Arons, A.B. (1983). Achieving wider scientific literacy. Daedalus, 112(2), 91-122.

Ashton, A. (1980). Balloons, solar energy and dyes: An approach to primary science. Education 3-13, 8(2), 7-11.

Association for Science Education. (1981). Education through science: The policy statement of the association for science education. School Science Review, 63(222), 5-52.

Austin, G.R. (1979). Exemplary schools and the search for effectiveness. Educational Leadership, 37(1), 10-14.

Awkerman, G., & Teller, P. (1979). Mess management for gifted students. Science and Children, 16(6), 10-11.

Ayers, J.B., & Ayers, M.N. (1973). Influences of S-APA on kindergarten children's use of logic in problem solving. School Science and Mathematics, 73(650), 768-771.

Ayers, J.B., & Mason, G.E. (1969). Differential effects of science: A process approach upon change in Metropolitan Readiness Test scores among kindergarten children. The Reading Teacher, 23, 435-439.

Baer, R.A., Jr. (1981-82). Clarifying my objections to values clarification: A response to Clifford E. Knapp. Journal of Environmental Education, 13(2), 5-11.

Baez, A.V. (1976). Innovation in science education--world-wide. Paris: UNESCO Press.

Baez, A.V. (1980). Curiosity, creativity, competence, and compassion: Guidelines for science education in the year 2000. In C.P. McFadden (Ed.), World trends in science education. Halifax, NS: Atlantic Institute of Education.

Baker, E.L. (1984). Can educational research inform educational practice? Yes! Phi Delta Kappan, 65(7), 453-455.

Baldwin, N.P., King, M.M., & West, N.F. (1982). Curriculum development in primary science: A catchment area model. School Science Review, 64(227), 350-353.

Barney, G. (Study Director). (1980). The global 2000 report to the president: Entering the twenty-first century. Washington, DC: U.S. Government Printing Office.

Barufaldi, J.P., Huntsberger, J.P., & Lazarowitz, R. (1976). Changes in attitude of preservice elementary education majors toward inquiry teaching strategies. School Science and Mathematics, 76(671), 420-424.

Barufaldi, J.P., & Swift, J. (1977). Children learning to read should experience science. The Reading Teacher, 80, 388-393.

Beard, J. (1971). The development of group achievement tests for two basic processes of AAAS Science--A Process Approach. Journal of Research in Science Teaching, 8(2), 179-183.

Beer, S. (1975). Platform for change. New York: Wiley.

Benham, N.B., Hosticka, A., Payne, J.D., & Yeotis, C. (1982). Making concepts in science and mathematics visible and viable in the early childhood curriculum. School Science and Mathematics, 82(1), 45-56.

Berkheimer, G.D., & Lott, G.W. (1984). Science educators' and graduate students' perceptions of science education objectives for the 1980's. Science Education, 68(2), 105-116.

Bethel, L.J., Ellis, J.D., & Barufaldi, J.P. (1982). The effects of a NSF institute on inservice teachers' views of science and attitudes toward environmental science education. Science Education, 66(4), 643-652.

Bethel, L.J., & Hord, S.M. (1981). A case of change: Inservice teachers in a national science foundation environmental science education program. In Abstract of papers presented at AERA, 1981. Washington, DC: American Educational Research Association

Bethel, L.J., & Hord, S.M. (1982). Preparing teachers to teach environmental science: An evaluation of a NSF program. Austin, TX: University of Texas. (ERIC Document Reproduction Service No. ED 216 866)

Biological Sciences Curriculum Study. (1977). Energy and society: Investigations in decision making, instructor's manual. Boulder, CO: Biological Sciences Curriculum Study.

Biological Sciences Curriculum Study. (1983). Education for the attainment and maintenance of optimal health: A proposal for the development and evaluation of a school (K-8) health education curriculum in Colorado. Boulder, CO: Biological Sciences Curriculum Study.

Black, P., Harlen, W., & Orgee, T. (1984). Standards of performance: Expectations and reality. Journal of Curriculum Studies, 16(1), 94-96.

Blackwood, P.E., & Porter, T.R. (1968). Evaluating science learning in the elementary school. Washington, DC: National Science Teachers Association.

Blin-Stoyle, R.J. (1984). Science for all: Implications for higher education. Physics Education, 19, 168-172.

Bloom, B.S. (1971). Mastery learning. In J. Block (Ed.), Mastery learning: Theory and practice. New York: Holt.

Bloom, B.S. (1976). Human characteristics and school learning. New York: McGraw-Hill.

Bloom, B.S. (1984). The search for methods of group instruction as effective as one-to-one tutoring. Educational Leadership, 41(8), 4-17.

Blosser, P.E. (1984). What research says: Achievement in science. School Science and Mathematics, 84(6), 514-521.

Blosser, P.E. (1985). Science education for the year 2000 and beyond. In R.K. James & V.R. Kurtz (Eds.), Science and mathematics education for the year 2000 and beyond. Bowling Green, OH: School Science and Mathematics Association.

Blosser, P.E. (1986). Meta-analysis research on science instruction. School Science & Mathematics, 86(2), 166-170.

Bodner, G.M., & Herron, J.D. (1980). Impressions of the McMaster conference on new directions in the chemistry curriculum. Journal of Chemical Education, 57(5), 349-350.

Bonnstetter, R.J., Penick, J.E., & Yager, R.E. (1984). Teachers in exemplary programs: How do they compare? Washington, DC: National Science Teachers Association.

Boulanger, F.D. (1981). Instruction and science learning: A quantitative synthesis. Journal of Research in Science Teaching, 18(4), 311-327.

Bowyer, J. (1984). Improving science education through staff development. In R. W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Boyd, E., & George, K.D. (1973). The effect of science inquiry on the abstract categorization behavior of deaf children. Journal of Research in Science Teaching, 10(9), 91-99.

Brandwein, P.F., Cross, B., & Neivert, S.S. (1985). Science and technology series. Coronado Publishing.

Bredderman, T. (1983). Effects of elementary-based science on student outcomes: A quantitative synthesis. Review of Educational Research, 53(4), 499-518.

Brooks, T., & Matthews, B.A. (1981). Improving practices in middle school science: Reaction I. In V.D. Ochs (Ed.), Improving practices in middle school science (1981 AETS Yearbook). Columbus, OH: Ohio State University, ERIC-SMEAC.

Brown, D.R. (1979). Teaching science to handicapped students: Learning by doing. In M.B. Rowe (Ed.), What research says to the science teacher: Vol. 2. Washington, DC: National Science Teachers Association.

Brown, F.K., & Butts, D.P. (Eds.). (1983). Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Bruner, J. (1960). The process of education. Cambridge, MA: Harvard University Press.

Bruner, J.S. (1971). The process of education reconsidered. Washington, DC: Association for Supervision and Curriculum Development.

Brunkhorst, H. (1985). Ethics, values and science teaching. In Bybee, R. (Ed.), Science technology society (1985 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Buccino, A. (1984). The condition of science education. Appraisal, 17(3), 4-12.

Buccino, A., & Evans, P.L. (1981). Comments from the science education directorate, National Science Foundation. Science Education, 65(2), 237-241.

Buros, O.K. (1978). The eighth mental measurements yearbook. Highland Park, NJ: Gryphon Press.

Bybee, R.W. (1974). Personalizing science teaching. Washington, DC: National Science Teachers Association.

Bybee, R.W. (1984). Human ecology: A perspective for biology education. Reston, VA: National Association of Biology Teachers.

Bybee, R.W. (Ed.). (1985a). Science-technology-society (1985 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Bybee, R.W. (1985b). The restoration of confidence in science and technology education. School Science and Mathematics, 85(2), 95-108.

Bybee, R.W., Carlson, J., & McCormack, A.J. (1984). Science and technology education: A review of contemporary reports. In R.W. Bybee, J. Carlson, & A.J. McCormack (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Bybee, R.W., & Hendricks, P.A. (1977). Teaching science concepts to preschool deaf children to aid language development. Science Education, 56(3), 303-310.

Bybee, R.W., Peterson, R., Bowyer, J., & Butts, D.P. (1984). Teaching about science and society: Activities for elementary and junior high school. Columbus OH: Merrill.

Bybee, R.W., & Yager, R.E. (1982). Perceptions of professional problems, proposed solutions and needed directions in science education. School Science and Mathematics, 82(8), 673-681.

Caduto, M. (1983). Toward a comprehensive strategy for environmental values education. Journal of Environmental Education, 14(4), 12-18.

Cain, S.E., & Evans, J.M. (1984). Sciencing: An involvement approach to elementary science methods (2nd ed.). Columbus, OH: Merrill.

California State Board of Education. (1978). Science framework for California public schools, kindergarten and grades one through twelve. Sacramento, CA: California State Board of Education.

California State Board of Education. (1982). Science education for the 1980s: A planning and assessment handbook for kindergarten through grade twelve. Sacramento, CA: California State Department of Education.

California State Board of Education. (1984). Science framework addendum for California public schools, kindergarten and grades one through twelve. Sacramento, CA: California State Board of Education.

Carey, R.L., & Stauss, N.G. (1968). An analysis of the understanding of the nature of science by prospective secondary science teachers. Science Education, 52(4), 358.

Carey, R.L., & Stauss, N.G. (1970). An analysis of experienced science teachers' understanding of the nature of science. School Science and Mathematics, 70(619), 366-376.

Carin, A.A., & Sund, R.B. (1980). Teaching science through discovery (4th ed.). Toronto, ON: Merrill.

Carrick, T. (1983). Some biology teachers' goals for advanced level teaching. Journal of Biological Education, 17(3), 205-214.

Carson, R. (1956). A sense of wonder. New York: Harper & Row.

Carter, C. (1982). A comparison of the effect of three instructional methods on achievement of biology students in a black southern college. In J.B. Kahle (Ed.), Double dilemma: Women and minorities in science education. West Lafayette, IN: Purdue Research Foundation.

Carter, G.S., & Simpson, R.D. (1978). Science and reading: A basic due. The Science Teacher, 45(3), 20.

Carter, J. (1984). Global resources, environment, and population. American Biology Teacher, 46(6), 305-309.

Catha, F.B. (1977). Children create fiction using science. Science and Children, 15(3), 22.

Champagne, A.B., & Klopfer, L.E. (1982a). A causal model of students' achievement in a college physics course. Journal of Research in Science Teaching, 19(4), 299-309.

Champagne, A.B., & Klopfer, L.E. (1982b). Actions in a time of crisis. Science Education, 66(4), 503-514.

Charles, C., & Samples, B. (1978). Science and society: Knowing, teaching, learning. Washington, DC: National Council for the Social Studies.

Chen, D., & Novik, R. (1984). Scientific and technological education in an information society--1983. Science Education, 68(4), 421-426.

Chetelat, F.J. (1979). Art and science: An interdisciplinary approach. Art Teacher, 9(3), 8.

Clark, R. C., & Premo, J.L. (1982). Results of Minnesota's statewide science assessment (1978-79). Science and Children, 19(7), 46-47.

Coble, C.R., Hounshell, P.B., & Adams, A.H. (1977). Mainstreaming science and mathematics: Special ideas and activities for the whole class. Santa Monica, CA: Goodyear Publishing Co., Inc.

Coble, C.R., Mattheis, F.E., & Vizzini, C.T. (1982). A project to promote science for the handicapped. School Science and Mathematics, 82(8), 692-701.

Coffia, W.J. (1971). The effects of an inquiry-centered curriculum in science on a child's achievement in school academic areas. Doctoral dissertation, University of Oklahoma.

Cohen, H., & Staley, F. (1982). Integrating with science: One way to bring science back into the elementary school day. School Science and Mathematics, 82(7), 565-572.

Cole, H., Jr., & Merrill, W. (1982). Science, technology, and general education. Journal of General Education, 34(3), 247-257.

Collette, A.T., & Chiappetta, E.L. (1984). Science instruction in middle and secondary schools. St. Louis: Mosby.

Connecticut State Board of Education. (1981). A guide to curriculum development in science education. Hartford, CT: Connecticut State Board of Education.

Connelly, F.M. (1985). A reader's guide to the study. In F.M. Connelly, R.K. Crocker, & H. Kass, Science education in Canada: Vol. I, Policies, practices, and perceptions. Toronto, ON: OISE Press.

Connelly, F.M., Crocker, R.K., & Kass, H. (1985). Science education in Canada: Vol. I, Policies, practices, and perceptions. Toronto, ON: OISE Press.

Crandall, D.P. (1983). The teacher's role in school improvement. Educational Leadership, 41(3), 6-9.

Crocker, R.K., & Banfield, H. (1985). Science teachers' perceptions. In F.M. Connelly, R.K. Crocker, & H. Kass, Science education in Canada: Vol. I, Policies, practices, and perceptions. Toronto, ON: OISE Press.

Davis, G.A., & Rimm, S.B. (1985). Education of the gifted and talented. Englewood Cliffs, NJ: Prentice-Hall.

Dede, C.J. (1983). Future challenges for science and mathematics education. School Science and Mathematics, 83(5), 363-374.

DeRose, J.V., Lockard, J.D., & Paldy, L.G. (1979). The teacher is the key: A report on three NSF studies. The Science Teacher, 46(6), 31-37.

Dillashaw, F.G., & Okey, J.R. (1980). Test of integrated process skills for secondary school students. Science Education, 64(5), 601-618.

Dillashaw, F.G., & Okey, J.R. (1983). Effects of a modified mastery learning strategy on achievement, attitudes, and on-task behavior of high school chemistry students. Journal of Research in Science Teaching, 20(3), 203-211.

Dolmatz, M.S., & Wong, H.K. (1976). Ideas and investigations in science: Physical science. Englewood Cliffs, NJ: Prentice-Hall.

Dowling, K.W., & Yager, R.E. (1983). Status of science education in state departments of education: An initial report. Journal of Research in Science Teaching, 20(8), 771-780.

Dukes, R.J., Jr., & Strauch, K. (1984). Trends in physics teaching. The Physics Teacher, 22(7), 446-456.

Dunkleberger, G.E., & Heikkinen, H.W. (1983). Mastery learning: Implications and practices. Science Education, 67(5), 553-560.

Duschl, R.A. (1983). The elementary level science methods course: Breeding ground of an apprehension toward science? A case study. Journal of Research in Science Teaching, 20(8), 745-754.

Elementary Science Study. (1969). Musical instrument recipe book. St. Louis, MO: McGraw-Hill.

El-Nemr, M.A. (1979). Meta-analysis of the outcomes of teaching biology as inquiry. Doctoral dissertation, University of Colorado, Boulder.

Enns, R. (1982). Crisis research in curriculum policy making: A conceptualization. Doctoral dissertation, University of Toronto.

Erb, T.O. (1981). Improving instructional practices through in-service: The university and in-service. In V.D. Ochs (Ed.), Improving instruction in middle school science (1981 AETS Yearbook). Columbus, OH: Ohio State University, ERIC-SMEAC.

Esler, W.K., & Anderson, B. (1981). Can science aid in remediating state assessment reading deficiencies? School Science and Mathematics, 81(710), 278-286.

Esler, W.K., & Esler, M.K. (1984), Teaching elementary science (4th ed.). Belmont, CA: Wadsworth.

Feistritzer, C.E. (1983). The condition of teaching: A state-by-state analysis. Princeton, NJ: Carnegie Foundation for the Advancement of Teaching.

Fensham, P.J. (1983). A research base for new objectives of science teaching. Science Education, 67(1), 3-12.

Fensham, P.J., & May, J.B. (1978). Servant not master: A new role for science in a core of environmental education. Australian Science Teachers Journal, 25(2), 15-24.

Finegold, M., & MacKeracher, D. (1985). The Canadian science curriculum. In F.M. Connelly, R.K.Crocker, & H. Kass, Science education in Canada: Vol. I, Policies, practices, and perceptions. Toronto, ON: OISE Press.

Fowler, J.M. (1975). Energy-environment sourcebook. Washington, DC: National Science Teachers Association.

Fraizer, K. (1983). Does school science enhance writing literacy? In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Fraser, B.J., & Walberg, H.J. (1981). Psychosocial learning environment in science classrooms: A review of research. Studies in science education, 8, 67-92.

Fraser, H. J. (1982). How strongly are attitude and achievement related? School Science Review, 63(224), 557-559.

Friend, H., Wisotsky, M., Sega, J., & Petosa, R. (1984). How does science and mathematics correlation in a seventh grade physics unit affect selected seventh grade students' attitudes toward and achievement in science. In Abstracts of papers presented at NARST, 1984. Columbus, OH: Ohio State University, ERIC-SMEAC.

Frischknecht, K., & Brandenburg, R. (1981-82). The systems approach in education with special consideration of environmental education: A review. Journal of Environmental Education, 13(2), 25-33.

Fullan, M. (1984). The meaning of educational change. Toronto, ON: OISE Press.

Fulton, H.F., Gates, R.W., & Krockover, G.H. (1980). An analysis of the teaching of science in the elementary school at this point in time: 1978-79. School Science and Mathematics, 80(8), 691-702.

Gabel, D.L., & Sherwood, R.D. (1983). Facilitating problem solving in high school chemistry. Journal of Research in Science Teaching, 20(2), 163-178.

Gabel, D.L., Sherwood, R.D., & Enochs, L. (1984). Problem-solving skills of high school chemistry students. Journal of Research in Science Teaching, 21(2), 221-233.

Gage, N.L. (1978). The scientific basis of the art of teaching. New York: Columbia University, Teachers College Press.

Gallagher, J.J. (1984). Educating high school teachers to instruct effectively in science and technology. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Gallagher, J.J., & Yager, R.E. (1980). Perceived problems of science educators for their discipline. Science Education, 64(5), 725-728.

Gallagher, J.J., Zehr, E., & Yager, R.E. (1983). Characteristics of personnel at graduate science education centers: Implications for the future of the profession. Journal of Research in Science Teaching, 20(4), 271-281.

Gardner, P. (1975). Attitudes to science. In D. Layton (Ed.), Studies in science education, 2. East Yorkshire, UK: University of Leeds, Centre for Studies in Education.

Gaskell, P.J. (1982). Science, technology, and society: Issues for science teachers. In D. Layton (Ed.), Studies in science education, 9. East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education.

Gega, P.C. (1982a). Convert your text series into a district science program. Science and Children, 20(3), 28-30.

Gega, P.C. (1982b). Science in elementary education (4th ed.). New York: Wiley.

Gennaro, E.G., & Glenn, A.D. (1975). Science and social studies: An interdisciplinary approach to values and value decisions. Science Education, 59(1), 85-93.

George, D.A. (1981). An engineer's view of science education. Ottawa, ON: Science Council of Canada.

Glass, G.V., Cohen, L.S., Smith, M.L., & Filby, N.N. (1982). School class size: Research and policy. Beverly Hills, CA: Sage Publications.

Good, R., Herron, J.D., Lawson, A.E., & Renner, J. W. (1985). The domain of science education. Science Education, 69(2), 139-141.

Good, T.L. (1979). Teacher effectiveness in the elementary school. Journal of Teacher Education, 30(2), 52-64.

Goodlad, J.I. (1963). Toward improved curriculum organization. In Planning and organizing for teaching. Washington, DC: National Education Association.

Goodlad, J.I. (1983). A place called school: Prospects for the future. New York: McGraw-Hill.

Graham, S.B. (1978). Do children read science books? Science and Children, 15(5), 29.

Grouws, D.A., & Thomas, W.E. (1981). Problem solving: A panoramic approach. School Science and Mathematics, 81(710), 307-314.

Guthrie, J.T. (1983). Science education research. Journal of Reading, 27(1), 92-94.

Hadary, D.E., & Cohen, S.H. (1978). Laboratory science and art for blind, deaf, and emotionally disturbed children: A mainstreaming approach. Baltimore, MD: University Park Press.

Haggerty, R.J. (1977). Changing lifestyles to improve health. Preventive Medicine, 6, 276-289.

Haggerty, S.M., & Hobbs, E.D. (1981). Analysis of science curricula in the provinces. Toronto, ON: Canadian Council of Ministers of Education.

Hall, P.Q. (1981). Problems and solutions in the education, employment, and personal choices of minority women in science. Washington, DC: American Association for the Advancement of Science.

Hall, R.T., & Davis, J.U. (1975). Moral education in theory and practice. New York: Prometheus Books.

Harlen, W. (1984). The impact of APU science work at LEA and school levels. Journal of Curriculum Studies, 16(1), 89-94.

Harlen, W., & Dahar, R.W. (1981). A scientific approach to the improvement of science teaching. Journal of Curriculum Studies, 13(2), 113-120.

Harms, N.C. (1981). Project synthesis: Summary and implications for teachers. In N.C. Harms & R.E. Yager (Eds.), What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Harms, N.C., & Yager, R.E. (Eds.). (1981). What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Harrison, A.J. (1982). In search of initiatives. Journal of Chemical Education, 59(9), 713-716.

Harshman, R.E. (1977). Project SCATE: Case studies of public school and public action programs. Columbus, OH: Ohio State University, ERIC-SMEAC.

Hart, E.P., Kesten, C., & Burgess, J.O. (1986). A comparison of the academic achievement of Saskatchewan high school graduates who intended to enter selected faculties at the University of Regina, 1982 and 1983. Regina, SK: Saskatchewan School Trustees Association.

Hart, K., Turner, A.D., & Booth, L. (1982). Case studies of four schools. Mathematics in Schools, 11(3), 10-12.

Harty, H., & Enochs, Z.G. (1985). Toward reshaping the inservice education of science teachers. School Science and Mathematics, 85(2), 125-135.

Harvey, G.D. (1977). A conceptualization of environmental education. In J.L. Aldrich et al. (Eds.), The report of the North American regional seminar on environmental education. Columbus, OH: Ohio State University, ERIC-SMEAC.

Hastings, J., & Stewart, J. (1983). An analysis of research studies in which "homemade" achievement instruments were utilized. Journal of Research in Science Teaching, 20(7), 697-703.

Hayes, R.E. (1985). A super model for teaching physics. The Physics Teacher, 23(5), 273-276.

Health Activities Project. (1982). Program of health activities. Northbrook, IL: Hubbard.

Helgeson, S.L., Blosser, P.E., & Howe, R.W. (1977). The status of pre-college science, mathematics, and social science education, 1955-75: Vol. 1, Science education. Columbus, OH: Ohio State University, Center for Science and Mathematics Education.

Herron, J.D., Jaus, H.H., Neie, V., Luce, T., & O'Heron, T. (1974). Science education: A summary of research in science education, 1974. New York: Wiley.

Hickman, F.M. (1977). Energy and society: Formative evaluation report. BSCS Newsletter, 67 (April), 7-17.

Hickman, F.M., & Kahle, J.B. (Eds.). (1982). New directions in biology teaching: Perspectives for the 1980's. Reston, VA: National Association of Biology Teachers.

Hochbaum, G. (1978). Some selected aspects of school health education. Health Education, 9(2), 32.

Hodson, D., & Prophet, R.B. (1983). Why the science curriculum changes--evolution or social control? School Science Review, 65(230), 5-18.

Hoffman, M.L., & Hoffman, L.W. (1964). Review of child development research. New York: Russell Sage Foundation.

Hofman, H. (1984). Resources for helping handicapped students. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Hofman, H., & Ricker, K. (1979). Science education and the physically handicapped. Washington, DC: National Science Teachers Association.

Hofstein, A., & Lunetta, V.N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. Review of Educational Research, 52(2), 201-217.

Hofstein, A., & Yager, R.E. (1982). Societal issues as organizers for science education in the '80s. School Science and Mathematics, 82(7), 539-547.

Holdzkom, D., & Lutz, P.B. (1984). Research within reach: Science education. Charleston, WV: Appalachia Educational Laboratory, Inc. (ERIC Document Reproduction Service No. ED 247 148)

Holliday, W.G., Helgeson, S.L., Blosser, P.E., & McGuire, B.L.S. (1985). A summary of research in science education, 1983. Science Education, 69(3), 275-419.

Holtz, R.E. (1976). More than a letter grade. Science and Children, 14(1), 23.

Hopkins, R.L. (1981). Implications for science and mathematics education of current philosophies of education. School Science and Mathematics, 81(4), 273-277.

Horn, T.D. (1966). Three methods of developing reading readiness in Spanish-speaking children in first grade. The Reading Teacher, 20(1), 38-42.

Howes, V.M. (Ed.). (1970). Individualizing instruction in science and mathematics. New York: Macmillan.

Huff, P., & Languis, M. (1973). The effects of the use of activities of S-APA on the oral communication skills of disadvantaged kindergarten children. Journal of Research in Science Teaching, 10(2), 165-173.

Hufstedler, S., & Langenberg, D.N. (1980). Science and engineering education for the 1980's and beyond. Washington, DC: National Science Foundation/United States Department of Education.

Humphreys, B., Johnson, R.T., & Johnson, D.W. (1982). Effects of cooperative, competitive, and individualistic learning on students' achievement in science class. Journal of Research in Science Teaching, 19(5), 351-356.

Hungerford, H.R., Peyton, R.B., & Wilke, R.J. (1980). Goals for curriculum development in environmental education. Journal of Environmental Education, 11(3), 42-47.

Hurd, P.D. (1969). New directions in teaching secondary school science. Chicago, IL: Rand McNally.

Hurd, P.D. (1973). "Futuring" about science teacher education. Science Education, 57(4), 517-519.

Hurd, P.D. (1976). The evolution of the BSCS human sciences curriculum. BSCS Newsletter, 63(April), 1-2.

Hurd, P.D. (1981). Biology education. In N.C. Harms & R.E. Yager (Eds.), What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Hurd, P.D. (1982). Transformation of science education: Challenges and criteria. Science Education, 66(2), 281-285.

Hurd, P.D. (1983a). Science education: The search for a new vision. Educational Leadership, 41(4), 20-22.

Hurd, P.D. (1983b). State of precollege education in mathematics and science. Science Education, 67(1), 57-68.

Hurd, P.D. (1984). Reforming science education: The search for a new vision. Washington, DC: Council for Basic Education.

Hurd, P.D. (1985). Science education for a new age: The reform movement. NASSP Bulletin, 69(482), 83-92.

Hurd, P.D. (1986). Perspectives for the reform of science education. Phi Delta Kappan, 67(5), 353-358.

Hurd, P.D., Bybee, R.W., Kahle, J.B., & Yager, R.E. (1980). Biology education in the secondary schools of the United States. American Biology Teacher, 42(7), 388-410.

Hurd, P.D., & Rowe, M.B. (1964). Science in the secondary school. Review of Educational Research, 34(3), 286-297.

Intermediate Science Curriculum Study. (1970). Various titles. Morristown, NJ: Silver Burdett.

Jackson, P.W. (1983). The reform of science education: A cautionary tale. Daedalus, 112(2), 143-166.

Jacobson, W.J., & Bergman, A.B. (1980). Science for children: A book for teachers. Englewood Cliffs, NJ: Prentice-Hall.

James, R.K. (1984). Preparing science teachers for the future. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Jennings, A. (1983). Biological education--the end of the dinosaur era? Journal of Biological Education, 17(4), 298-302.

Johnson, G. (1983). Does science in the elementary school facilitate the goals of schooling? In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Johnson, R.T., & Johnson, D.W. (1982). What research says about student-student interaction in science classrooms. In M.B. Rowe (Ed.), Education in the 80's: Science. Washington, DC: National Education Association.

Johnston, J. (1984). Meeting science education goals with 3-2-1 CONTACT. Science and Children, 21(7), 38-39.

Kahle, J.B. (1982). The disadvantaged majority: Biology education for women and minorities. American Biology Teacher, 44(6), 351-357.

Kahle, J.B., & Lakes, M.K. (1983). The myth of equality in science classrooms. Journal of Research in Science Teaching, 20(2), 131-140.

Kahle, J.B., & Yager, R.E. (1981). Current indicators for the discipline of science education. Science Education, 65(1), 25-31.

Karen, T. (1978). Biological studies in art. American Biology Teacher, 40, 160.

Katz, G., & Bushnell, S. (1979). Meeting special needs through environmental education. Teaching Exceptional Children, 11(3), 110-113.

Keller, F.S., & Sherman, J.G. (1974). The Keller plan handbook. Meno Park, CA: W.A. Benjamin, Inc.

Kelly, A. (1981). Retrieving the missing half. In A. Kelly (Ed.), The missing half: Girls and science education. Manchester, UK: University of Manchester Press.

Kirman, J.M., & Nay, M.A. (1975). Joint planning for integrating social studies and science. Social Education, 39(2), 77-80.

Klopfer, L.E. (1971). Evaluation of learning in science. In B.S. Bloom, J. Hastings, & G. Madaus (Eds.), Handbook of formative and summative evaluation. New York: McGraw-Hill.

Klopfer, L.E. (1976). A structure for the affective domain in relation to science education. Science Education, 60(3), 299-312.

Knight, C.W. (1977). Science activities as stimulators of creative writing. Journal of Creative Behavior, 11(3), 214.

Knutsen, L. (1979). Teaching fifty gifted science units in two easy steps. Science and Children, 16(6), 51-53.

Koballa, T.R., Jr. (1984). Goals of science education. In D. Holdzkom, & P.B. Lutz (Eds.), Research within reach: Science education. Washington, DC: National Science Teachers Assocation.

Koballa, T.R., Jr., & Bethel, L.J. (1984). Integration of science and other school subjects. In D. Holdzkom & P.B. Lutz (Eds.), Research within reach: Science education. Washington, DC: National Science Teachers Association.

Kohlberg, L. (1973). The child as moral philosopher. In J.F. Soltis (Ed.), Moral education. New York: Columbia University Press.

Kremer, B.K., & Walberg, H.T. (1981). A synthesis of social and psychological influences on science learning. Science Education, 65(1), 11-21.

Kromhout, R., & Good, R. (1983). Beware of societal issues as organizers for science education. School Science and Mathematics, 83(8), 647-650.

Kuhn, D.J. (1979). Giving gifted children their due. The Science Teacher, 46(2), 32-34.

Kyle, W.C., Jr. (1984). Curriculum development projects of the 1960s. In D. Holdzkom & P.B. Lutz (Eds.), Research within reach: Science education. Washington, DC: National Science Teachers Association.

Kyle, W.C., Jr., Shymansky, J.A., & Alport, J.M. (1982). Alphabet soup science: A second look at the NSF-funded science curricula. The Science Teacher, 49(8), 49-53.

Lapointe, A.E. (1984). The good news about American education. Phi Delta Kappan, 65(10), 663-668.

Larkin, H.J., & Brackett, G.C. (1974). Mathematics prerequisites: A mastery approach. American Journal of Physics, 42, 1089-1091.

Layton, D. (Ed.). (1982). Studies in science education, 9. East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education.

Leeper, F. (1984). Integrating biology and English. American Biology Teacher, 46(5), 280-282.

Levi, I. (1960). Must the scientist make value judgments? Journal of Philosophy, 57, 345-357.

Levin, J., & Fowler, H.S. (1984). Sex, grade, and course differences in attitudes that are related to cognitive performance in secondary science. Journal of Research in Science Teaching, 21(2), 151-166.

Linn, M.C., & Peterson, R.W. (1973). The effect of direct experiences with objects on middle class, culturally diverse, and visually impaired young children. Journal of Research in Science Teaching, 10(1), 83-90.

Long, N.T. (1973). Science Curriculum Improvement Study (SCIS): Its effect on concept development and manipulative skills in visually handicapped children. Dissertation Abstracts International, 34, 1738A.

Lott, G.W. (1983). The effect of inquiry teaching and advance organizers upon student outcomes in science education. Journal of Research in Science Teaching, 20(5), 437-451.

Lucas, A.M. (1980). Science and environmental education: Pious hopes, self praise and disciplinary chauvinism. In D. Layton (Ed.), Studies in science education, 7. East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education.

Lucas, A.M. (1980-81). The role of science education in education for the environment. Journal of Environmental Education, 12(2), 33-37.

Lucas, K.B. (1981). Science curriculum objectives for the future. Science Education, 65(3), 317-322.

Lucas, S.B., & Burlando, A.D. (1975). The new science methods and reading. Language Arts, 52, 769-770.

Lueckemeyer, C.L., & Chiappetta, E.L. (1981). An investigation into the effects of a modified mastery strategy on achievement in a high school human physiology unit. Journal of Research in Science Teaching, 18(3), 269-273.

MacKeracher, D. (1985). Science education in a changing society. In F.M. Connelly, R.K. Crocker, & H. Kass, Science Education in Canada: Vol. I, Policies, practices, and perceptions. Toronto, ON: OISE Press.

MacKeracher, D., & Jantzi, D. (1985). Policies and objectives in science education. In F.M. Connelly, R.K. Crocker, & H. Kass, Science education in Canada: Vol. 1, Policies, practices, and perceptions. Toronto, ON: OISE Press.

Magary, J., & Freehill, F. (1972). Critical questions and answers relating to school and society in the education of the gifted. Gifted Child Quarterly, 16(3), 185-194.

Malitza, M. (1982). Coming changes in science and the curricula. Prospects Quarterly Review of Education, 12(1), 89-100.

Manitoba Department of Education. (1980). Manitoba science assessment program 1980: Final report. Winnipeg, MB: Department of Education. (ERIC Document Reproduction Service No. ED 256 563)

Marchese, R.S. (1977). A literature search and review of the comparison of individualized and conventional modes of instruction in science. School Science and Mathematics, 77(8), 669-703.

Marshall, G. (1984). Evaluation of student progress. In D. Holdzkom, & P.B. Lutz (Eds.), Research within reach: Science education. Washington, DC: National Science Teachers Association.

Marx, G. (1983). What is physics? Physics Education, 18(1), 7-13.

Maryland State Department of Education. (1984). Science: A Maryland curricular framework. Baltimore, MD: Maryland State Department of Education. (ERIC Document Reproduction Service No. ED 256 625).

Matray, P., & Knorr, S. (1980). BIO/ART: A team-teaching approach for secondary schools. American Biology Teacher, 42, 477-481.

Matyas, M.L. (1984). Improving precollegiate science education for women and minorities: Adding encouragement and subtracting stereotypes. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Mayer, V. (1974). Unpublished evaluation instruments in science education: A handbook. Columbus OH: Ohio State University, Center for Science, Mathematics & Environmental Education.

Mayer, W.V. (1979). Forward to fundamentals. American Biology Teacher, 41(4), 204-209.

McCarthy, B. (1982). Improving staff development through CBAM and 4 Mat. Educational Leadership, 40(1), 20-25.

McConnell, M. (1982). Teaching about science, technology and society at the secondary school level in the United States: An educational dilemma for the 1980s. In D. Layton (Ed.), Studies in science education, 9. East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education.

McDermott, L.C. (1982). Problems in understanding physics (kinematics) among beginning college students--with implications for high school courses. In M.B. Rowe (Ed.), Education in the 80's: Science. Washington, DC: National Education Association.

McInerney, J.D. (1979). Human genetics education: Background and rationale. BSCS Journal, 2(2), 2-6.

McInnis, N., & Albrecht, D. (1975). What makes education environmental? Louisville, KY: Data Courier Inc.

McLean, L., Crocker, R., & Winne, P.H. (1984). Research on teaching in Canada: Some projects and prospects (Informal Series 58). Toronto, ON: OISE Press.

Mechling, K.R., & Oliver, D.L. (1982-83). Activities, not textbooks: What research says about science programs. Principal, 62(4), 41-43.

Mechling, K.R., & Oliver, D.L. (1983). Handbook I: Science teaches basic skills; Handbook II: The principal's role in elementary school science; Handbook III: Characteristics of a good elementary science program, Parts A and B; and Handbook IV: What research says about elementary school science. Washington, DC: National Science Teachers Association.

Mechling, K. R., Stedman, C.H., & Donnellan, K.M. (1982). Preparing and certifying science teachers. Science and Children, 20(2), 9-14.

Medvitz, A.G., & Watson, F.G. (1979). The influence of professional associations on science teaching. In M.R. Abraham (Ed.), Science education/society: A guide to interaction and influence (1979 AETS Yearbook). Columbus, OH: Ohio State University, ERIC-SMEAC.

Mendelsohn, E. (1976). Values and science: A critical reassessment. The Science Teacher, 43(1), 20-23.

Miles, J.C. (1978). Study of values in environmental education. Journal of Environmental Education, 9(2), 165-174.

Miller, J., Suchner, R., & Voelker, A.M. (1980). Citizenship in an age of science. Elmsford, NY: Pergamon Press.

Miller, J.D. (1983). Scientific literacy: A conceptual and empirical review. Daedalus, 112(2), 29-48.

Miller, R.M. (1984). Science teaching for the citizen of the future, 1983. Science Education, 68(4), 403-410.

Minstrell, J. (1982). Conceptual development research in the natural setting of a secondary school science classroom. In M.B. Rowe (Ed.), Education in the 80's: Science. Washington, DC: National Education Association.

Mohlman, G.G., Kierstead, J., & Gundlach, M. (1982). A research-based inservice model for secondary teachers. Educational Leadership, 40(1), 16-19.

Molloy, L. (1976). Law and the handicapped. Science and Children, 13(6), 7-10.

Munby, H. (1983). Thirty studies involving "scientific attitude inventory": What confidence can we have in this instrument? Journal of Research in Science Teaching, 20, 141-162.

Nadeau, R., & Desautels, J. (1984). Epistemology and the teaching of science. Ottawa, ON: Science Council of Canada.

National Assessment of Educational Progress. (1978). Changes in achievement, 1969-1977: Selected results from the third national assessment of science. Denver, CO: Center for Assessment of Educational Progress.

National Assessment of Educational Progress. (1979). Attitudes toward science: A summary of the results of the 1976-77 national assessment of science. Denver, CO: Education Commission of the States.

National Assessment of Educational Progress. (1979). Science objectives for the third assessment. Denver, CO: Education Commission of the States.

National Commission on Excellence in Education. (1983). A nation at risk. Washington, DC: U.S. Gov't Printing Office.

National Council of Social Studies. (1984). Social studies and the education of citizens. Social Education, 48, 250.

National Council of Teachers of Mathematics. (1980). An agenda for action: Recommendations for school mathematics of the 1980's. Reston, VA: National Council of Teachers of Mathematics.

National Science Board Commission. (1983). Precollege education in mathematics, science, and technology: Conference on goals for science and technology education, grades K-12. Washington, DC: National Science Foundation.

National Science Foundation. (1982). Science and engineering education: Data and information. Washington, DC: Office of Scientific and Engineering Personnel and Education.

National Science Foundation. (1983). A revised and intensified science and technology curriculum grades K-12 urgently needed for our future. Washington, DC: National Science Foundation.

National Science Teachers Association. (1978a). Guidelines for self-assessment of secondary science programs. Washington, DC: National Science Teachers Association.

National Science Teachers Association (1978b). Science education: Accomplishments and needs. Columbus, OH: Ohio State University, ERIC-SMEAC.

National Science Teachers Association. (1982). Science-technology-society: Science education for the 1980s (NSTA Position Statement). Washington, DC: National Science Teachers Association.

National Science Teachers Association. (1983a). Position statement on science-technology-society: Science education for the 1980s. In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

National Science Teachers Association. (1983b). Recommended standards for the preparation and certification of teachers of science at the elementary and middle/junior high school levels. Washington, DC: National Science Teachers Association.

Nelkin, D. (1982). Science and technology policy and the democratic process. In D. Layton (Ed.), Studies in science education, 9. East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education.

Neuman, D.B. (1974). You don't have time not to teach science. Science and Children, 12(3), 29-31.

Neuman, D.B. (1981). Elementary science for all children: An impossible dream or a reachable goal? Science and Children, 18(6), 4-6.

Nicodemus, R.B. (1968). An evaluation of elementary science study as Science--A Process Approach. Washington, DC: Washington Academy of Science. (ERIC Document Reproduction Service No. ED 027 217)

Ochs, V.D. (Ed.). (1981). Improving practices in middle school science (1979 AETS Yearbook). Columbus, OH: Ohio State University, ERIC-SMEAC.

Olson, J., & Russell, T. (Eds.). (1984). Science education in Canadian schools: Vol. III, Case studies in science teaching. (Background Study 52). Ottawa, ON: Science Council of Canada.

Olstad, R.G., & Haury, D.L. (1984). A summary of research in science education, 1982. Science Education, 68(3), 207-363.

Opel, J.R. (1982). Education, science and national economic competitiveness. Science, 217, 1116-1117.

Orpwood, G.W.F. (1980). Deliberative inquiry into Canadian science education. Journal of Curriculum Studies, 12(4), 363-364.

Orpwood, G.W.F. (1985). Toward the renewal of Canadian science education: I. The deliberative inquiry model. Science Education, 69(4), 477-490.

Orpwood, G.W.F., & Alam I. (1984). Science education in Canadian schools: Vol. II, Statistical database for Canadian science education (Background Study 52). Ottawa, ON: Science Council of Canada.

Orpwood, G.W.F., & Souque, J.P. (1984). Science education in Canadian schools: Vol. I, Introduction and curriculum analyses (Background Study 52). Ottawa, ON: Science Council of Canada.

Page, J.E. (1979). A Canadian context for science education. Ottawa, ON: Science Council of Canada.

Pellicano, R.R. (1983). Literacy for modern times. Educational Leadership, 41(4), 67-69.

Penick, J.E. (Ed.). (1983a). Focus on excellence: Science as inquiry (Report No. 1). Washington, DC: National Science Teachers Association.

Penick, J.E. (Ed.). (1983b). Focus on excellence: Elementary science (Report No. 2). Washington, DC: National Science Teachers Association.

Penick, J.E. (1986). 10 exemplary S/T/S programs. Curriculum Review, 24(3), 22-23.

Penick, J.E., & Bonnstetter, R.J. (Eds.). (1984). Focus on excellence: Biology (Report No. 3). Washington, DC: National Science Teachers Association.

Penick, J.E., & Johnson, R.T. (1983). Excellence in teaching science: Some generalizations and recommendations. In J.E. Penick (Ed.), Focus on excellence: Elementary science (Report No. 2). Washington, DC: National Science Teachers Association.

Penick, J.E., & Kyle, W.C., Jr. (1982). Societal and educational applications of biological concepts. Journal of College Science Teaching, 11(5), 302-303.

Penick, J.E., & Lunetta, V.N. (Eds.). (1984). Focus on excellence: Physical science (Report No. 4). Washington, DC: National Science Teachers Association.

Penick, J.E., & Meinhard-Pellen, R. (Eds.). (1984). Focus on excellence: Science/technology/society (Report No. 5). Washington, DC: National Science Teachers Association.

Penick, J.E., & Yager, R.E. (1983). The search for excellence in science education. Phi Delta Kappan, 64(9), 621-623.

Pennsylvania State Department of Education. (1984). Science unlimited: Pennsylvania's resource guide for elementary science. Harrisburg; PA: Pennsylvania State Department of Education. (ERIC Document Reproduction Service No. ED 182 465)

Peterson, P.L., Marx, R.W., & Clark, C.M. (1978). Teacher planning, teacher behavior, and student achievement. American Educational Research Journal, 15(3), 417-432.

Peterson, P.L., & Walberg, H.J. (Eds.). (1979). Research on teaching: Concepts, findings, and implications. Berkeley, CA: McCutchan.

Peterson, R., Bowyer, J., Butts, D., & Bybee, R. (1984). Science and society: A source book for elementary and junior high school teachers. Columbus, OH: Merrill.

Peterson, R.W., & Carlson, G.R. (1979). A summary of research in science education, 1977. Science Education, 63(4), 429-553.

Piaget, J. (1932). The moral judgment of the child. New York: Harcourt, Brace & Co.

Piel, E.J. (1981). Interaction of science, technology, and society in secondary schools. In R.E. Yager (Ed.), What research says to the science teacher: Vol. 4. Washington, DC: National Science Teachers Association.

Polanyi, M. (1958). Personal knowledge. London, UK: Routledge and Kegan Paul.

Pratt, H. (1981). Science education in the elementary school. In N.C. Harms & R.E. Yager (Eds.), What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Press, F. (1982). The fate of school science. Science, 216, 1055.

Pryt, M.C. (1979). Helping scientifically gifted students. Science and Children, 16(6), 16-17.

Purkey, S.C., & Smith, M.S. (1982). Too soon to cheer? Synthesis of research on effective schools. Educational Leadership, 40(3), 64-69.

Rakow, S.J., Wech, W.W.,& Hueftle, S.J. (1984). Student achievement in science: A comparison of national assessment results, 1984. Science Education, 68(5), 571-584.

Ramsey, J., Hungerford, H.R., & Tomera, A.N. (1981). The effects of environmental action and environmental case study instruction on the overt environmental behavior of eighth-grade students. Journal of Environmental Education, 13(1), 24-29.

Redden, M.R. (1984). Science education for handicapped children. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Reed, J.A. (1971). Integrating the teaching of science and mathematics in the elementary school. School Science and Mathematics, 71(8), 725-730.

Reid, H.K., & McGlathery, G. (1977). Science and creative writing. Science and Children, 14(4), 19-20.

Renner, J.W. (1971). SCIS helps the first grader to use logic in problem solving. School Science and Mathematics, 71(2), 159-164.

Renner, J.W. (1976). A summary of research in science education, 1976. Science Education, 60(3), 1-143.

Renner, J.W., Stafford, D.G., Coffia, W.J., Kellogg, D.H., & Weber, M.C. (1973). An evaluation of the science curriculum improvement study. School Science and Mathematics, 73(4), 291-318.

Renner, J.W., Stafford, D.G., Lawson, A.E., McKinnon, J.W., Friot, F.E., & Kellogg, D.H. (1976). Research, teaching, and learning with the Piaget model. Norman, OK: University of Oklahoma.

Roberts, D.A. (1982). Developing the concept of "curriculum emphases" in science education. Science Education, 66(2), 243-260.

Roberts, D.A. (1983). Scientific literacy: Towards balance in setting goals for school science programs. Ottawa, ON: Science Council of Canada.

Robinson, J.T. (1969). Philosopohical and historical bases of science teaching. Review of Educational Research, 39(4), 459-471.

Roderiguez I., & Bethel, L.J. (1983). An inquiry approach to science and language teaching. Journal of Research in Science Teaching, 20(4), 291-296.

Rolls, H.F. (1984). The future of science education: An alternative perspective. School Science Review, 65(232), 429-439.

Rosenshine, B.V. (1979). Content, time, and direct instruction. In P.L. Peterson & H.L. Walberg (Eds.), Research on teaching: Concepts, findings, and implications. Berkeley, CA: McCutchan.

Rosenthal, D.B. (1979). A "science and society" course for high school students. American Biology Teacher, 41(6), 336-340.

Rowe, M.B. (1968). SCIS in the inner-city school. Science Curriculum Improvement Study Newsletter, 11(3), 6-7.

Rowe, M.B. (1973). Teaching science as continuous inquiry. New York: McGraw-Hill.

Rowe, M.B. (1974a). Relation of wait-time and rewards to the development of language, logic, and fate control. Journal of Research in Science Teaching, 11(4), 291-308.

Rowe, M.B. (1974b). Wait-time and rewards as instructional variables: Their influence on language, logic, and fate control. Journal of Research in Science Teaching, 11(2), 81-94.

Rowe, M.B. (1983). Science education: A framework for decision-makers. Daedalus, 112(2), 123-142.

Roy, R. (1986). The science/technology/society connection. Curriculum Review, 24(3), 12-16.

Rudner, R. (1953). The scientist makes value judgments. Philosophy of Science, 20, 1-6.

Saskatchewan Education. (1971a). Science: A curriculum guide for divisions I and II. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1971b). Modern biology, (Biology 20, 30): A curriculum guide for division IV. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1974). Accreditation policies. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1976a). Chemistry 20 and 30: A curriculum guide for division IV. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1976b). Physics 20 and 30: A curriculum guide for division IV. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1979). Science: A curriculum guide for division III. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1980). Science 10: A curriculum guide for division IV. Regina, SK: Saskatchewan Education.

Saskatchewan Education. (1984a). Directions: The final report. Regina, SK: Saskatchewan Education, Curriculum and Instruction Review.

Saskatchewan Education. (1984b). Saskatchewan children: Their lives and needs (Report No. 3). Regina, SK: Saskatchewan Education, Curriculum and Instruction Review.

Saskatchewan Education. (1984c). Saskatchewan education: Its programs and policies (Report No. 2). Regina, SK: Saskatchewan Education. Curriculum and Instruction Review.

Saskatchewan Education. (1984d). What they said: Educational views of Saskatchewan people (Report No. 1). Regina, SK: Saskatchewan Education, Curriculum and Instruction Review.

Saskatchewan Education. (1985a). School improvement: Building a more effective learning environment (Report No. 5). Regina, SK: Saskatchewan Education, Curriculum and Instruction Review.

Saskatchewan Education. (1985b). Toward the year 2000: Future directions in curriculum and instruction (Report No. 4). Regina, SK: Saskatchewan Education, Curriculum and Instruction Review.

Saskatchewan Education. (1986). Program policy proposals: Report of the core curriculum advisory committee. Regina, SK: Saskatchewan Education.

Schneider, L.S., & Renner, J.W. (1980). Concrete and formal teaching. Journal of Research in Science Teaching, 17(6), 503-517.

Schwab, J.J. (1983). The practical 4: Something for curriculum professors to do. Curriculum Inquiry, 13(3), 239-265.

Science Council of Canada. (1984). Science for every student: Educating Canadians for tomorrow's world (Report No. 36). Ottawa, ON: Science Council of Canada.

Scruggs, T.E., Mastropieri, M.A., Levin, J.R., & Gaffney, J.S. (1985). Facilitating the acquisition of science facts in learning disabled students. American Educational Research Journal, 22(4), 575-586.

Searles, W.E. (1982). A substantiation of Macdonald's models in science curriculum development. Journal of Curriculum Theorizing, 4(1), 127-155.

Searles, W.E. (1984). Considerations for science, technology, and society curriculum in North America. Prospects, 14(4), 541-549.

Seldin, C.A. (1979). Taking inservice education off the back burner. Phi Delta Kappan, 61(4), 266-287.

Seymour, R.D. (1981). Ethical uses of scientific knowledge: An instructional TV unit for high school. In Sourcebook of projects: Science education development and research. Washington, DC: National Science Foundation.

Shakhashiri, B.Z. et al. (1983). General lectures: Looking ahead, looking around, looking back. Journal of Chemical Education, 60(1), 4-5.

Shamos, M.H. (1983). You can lead a horse to water... Educational Leadership, 41(4), 30-33.

Shann, M.H. (1977). Evaluation of an interdisciplinary problem-solving curriculum in elementary science and mathematics. Science Education, 61(4), 491-502.

Shavelson, R.J., & Stern, P. (1981). Research on teachers' pedagogical thoughts, judgments, decisions, and behavior. Review of Educational Research, 51(4), 455-498.

Shayer, M., & Adey, P. (1981). Towards a science of science teaching: Cognitive development and curriculum demand. London, UK: Heinemann.

Showalter, V.M. (1974). Program objectives and scientific literacy (Parts 5 and 6). Prism II (Newsletter of the Center for Unified Science Education), 2(1) (Spring/Summer).

Shrigley, R.G. (1983). Persuade, mandate, and reward: A paradigm for changing the science attitudes and behaviors of teachers. School Science and Mathematics, 83(3), 204-215.

Shymansky, J.A., Kyle, W.C., Jr., & Alport, J.M. (1982a). How effective were the hands-on science programs of yesterday? Science and Children, 20(3), 14-15.

Shymansky, J.A., Kyle, W.C., Jr., & Alport, J.M. (1982b). Research synthesis on the science curriculum projects of the sixties. Educational Leadership, 40(1), 63-66.

Shymansky, J.A., Kyle, W.C., Jr., & Alport, J.M. (1983). The effects of new science curricula on student performance. Journal of Research in Science Teaching, 20(5), 387-404.

Skolnick, J., Langbort, C., & Day, L. (1982). How to encourage girls in math & science. Englewood Cliffs, NJ: Prentice-Hall.

Simon, M.S., & Zimmerman, J.M. (1980). Science and writing. Science and Children, 18(3), 7-9.

Simpson, E.J. (1972). The classification of educational objectives in the affective domain. In The psychomotor domain: A resource book for media specialists. Washington, DC: Gryphon House.

Simpson, R.D., & Anderson, N.D. (1981). Science, students, and schools: A guide for the middle and secondary school teacher. New York: Wiley.

Sipe, H.C., & Farmer, W.A. (1982). A summary of research in science education, 1980. Science Education, 66(3), 303-501.

Smith, A., & Halton, J.T. (1978). Science curriculum: Shot-gun or rifle approach. Canadian Vocational Journal, 13(4), 26-28, 31-32.

Smith, M.R. (1982). Science for the native orientated classroom. Journal of American Indian Education, 21(3), 13-17.

Social Studies Education Consortium. (1980). Social studies priorities, practices, and needs (SPAN). Boulder, CO: Social Studies Education Consortium, Inc.

Society, Environment & Energy Development Studies Foundation. (1981-83). SEEDS curriculum materials. Toronto, ON: Science Research Associates (Canada) Limited.

Squires, D.A., Huitt, W.G., & Segars, J.K. (1981). Improving classrooms and schools: What's important. Educational Leadership, 39(3), 174-179.

Stake, R.E., & Easley, J.A., Jr. (1978). Case studies in science education, Vol. I and II. Urbana, IL: University of Illinois, Center for Instructional Research and Curriculum Evaluation.

Stallings, J. (1982). Applications of classroom research of the 1970s to mathematics and science instruction. In R.E. Yager (Ed.), What research says to the science teacher: Vol. 4. Washington, DC: National Science Teachers Association.

Stapp, W.B., & Cox, D.A. (1982). Environmental education activities manual. Farmington Hills, MI: Stapp & Cox Inc.

Staver, J.R. (1984). Research on formal reasoning patterns in science education: Some messages for science teachers. School Science and Mathematics, 84(7), 573-589.

Steinkamp, M.W., & Maehr, M.L. (1983). Affect, ability and science achievement: A quantitative synthesis of correlational research. Review of Educational Research, 53(3), 369-396.

Stemmler, A.O. (1966). An experimental approach to the teaching of oral language arts and reading. Harvard Education Review, 36, 42-59.

Stenhouse, L. (1975). An introduction to curriculum research and development. London, UK: Heinemann.

Stratemeyer, F.B., Forkner, H. L., McKim, M.G., & Passow, A.H. (1957). Developing a curriculum for modern living (2nd ed.). New York: Teachers College Press.

Stronck, D.R. (1985). Recommendations of British Columbia science teachers for revising teacher education programs. Science Education, 69(2), 247-257.

Stulp, C. (1976). One-to-one communication. Science and Children, 13(5), 12-13.

Sunal, C.S. (1982). Philosophical bases for science and mathematics in early childhood education. School Science and Mathematics, 82(1), 2-10.

Sunal, D.W. (1982). Cognitive development and academic achievement in hearing impaired early adolescents. In Abstracts of papers presented at NARST, 1982. Columbus, OH: Ohio State University, ERIC-SMEAC.

Swanson, D., & Denton, J. (1977). Learning for mastery versus personalized system of instruction: A comparison of remediation strategies with secondary school chemistry students. Journal of Research in Science Teaching, 14(6), 515-524.

Sweeney, J. (1982). Research synthesis on effective school leadership. Educational Leadership, 39, 346-352.

Taba, H. (1962). Curriculum development: Theory and practice. New York: Harcourt, Brace, Jovanovich.

Tannenbaum, H.E., Stillman, N., & Piltz, A. (1965). Science education for elementary school teachers (2nd ed.). Boston: Allyn & Bacon.

Tanner, R.T. (1974). Ecology, environment and education. Lincoln, NE: Professional Educators Publications Inc.

Taylor, H. (1982). The 1982 British Columbia science assessment general report. Victoria, BC: Queen's Printer for British Columbia.

Thelen, L.J. (1983). Values and valuing in science. Science Education, 67(2), 185-192.

Thier, H.D. (1970). Teaching elementary school science: A laboratory approach. Lexington, MA: Heath.

Thier, H.D. (1984). The science curriculum in the future: Some suggestions for experience-centered instruction in the fifth through ninth grades. In R. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Thier, H.D. (1985). Societal issues and concerns: A new emphasis for science education. Science Education, 69(2), 155-162.

Tipps, S. (1980). Making better guesses: A goal in early childhood science. School Science and Mathematics, 82(1), 29-37.

Tipps, S. (1982). Formal operational thinking of gifted students in grades 5, 6, 7, and 8. In Abstracts of papers presented at NARST, 1982. Columbus, OH: Ohio State University, ERIC-SMEAC.

Tisher, R., & Dale, L. (1975). Understanding in science test. Hawthorn, Victoria: Australian Council for Educational Research.

Tobin, K.G. (1980). The effects of variations in teacher wait-time and questioning quality on integrated science process achievement for middle school students of differing formal reasoning ability and locus of control. Dissertation Abstracts International, 41, 1520A.

Tobin, K.G., & Capie, W. (1981). The development and validation of a group test of logical thinking. Educational and Psychological Measurement, 41(2), 413-423.

Triezenberg, H.J. (Ed.). (1972). Individualized science: Like it is. Washington, DC: National Science Teachers Association.

Trowbridge, L.W. (1984). New challenges for preservice teacher education. In R.W. Bybee et al. (Eds.), Redesigning science and technology education (1984 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Tyler, R. (1949). Principles of curriculum and instruction. Chicago, IL: The University of Chicago Press.

Ukens, L. (1983). Does science teacher preparation nurture effective science teaching? In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

UNESCO. (1981). International congress on science and technology education and national development. Paris, France: UNESCO.

UNESCO-UNEP. (1976). The Belgrade charter: A global framework for environmental education. Connect, 1(1), 1-2. Paris, France: UNESCO-UNEP (United Nations Environmental Program).

Voelker, A.M. (1982). The development of an attentive public for science: Implications for science teaching. In R.E. Yager (Ed.), What research says to the science teacher: Vol.4. Washington, DC: National Science Teachers Association.

Volk, T.L. (1984). Project Synthesis and environmental education. Science Education, 68(1), 23-33.

Voss, B.E. (1980). Objectives for middle school science. School Science and Mathematics, 80(7), 573-576.

Wagner, P.A. (1983). The nature of paradigmatic shifts and the goals of science education, 1983. Science Education, 67(5), 605-613.

Walberg, H.J. (1984). Improving the productivity of America's schools. Educational Leadership, 41(8), 19-27.

Walberg, H.J., Schiller, D., & Haertel, G.D. (1979). The quiet revolution in educational research. Phi Delta Kappan, 61(3), 179-183.

Walford, E.T. (1983). High school chemistry: Preparation for college or preparation for life? Journal of Chemical Education, 60(12), 1053-1055.

Wall, J., & Summerlin, L. (1973). Standardized science tests: A descriptive listing. Washington, DC: National Science Teachers Association.

Watson, F. (1983). On the drawing board: A 21st century curriculum. The Science Teacher, 50(3), 62-63.

Watts, M., & Bentley, D. (1984). The personal parameters of cognition: Two personal aims in science education. Oxford Review of Education, 10(3), 309-317.

Webber, M.D., & Renner, J.W. (1972). How effective is the SCIS science program? School Science and Mathematics, 72(640), 729-734.

Weinstein, T., Boulanger, F.D., & Walberg, H.J. (1982). Science curriculum effects in high school: A quantitative synthesis. Journal of Research in Science Teaching, 19(6), 511-522.

Weiss, I.R. (1978). Report of the 1977 national survey of science, mathematics, and social studies education. Research Triangle Park, NC: Center for Educational Research and Evaluation.

Welch. W.W. (1979). Twenty years of science curriculum development: A look back. In D. Berlinger (Ed.), Review of research in education. Washington, DC: American Educational Research Association.

Welch, W.W. (1985). Research in science education: Review and recommendations. Science Education, 69(3), 421-448.

Welch, W.W., Klopfer, L.E., Aikenhead, G.S., & Robinson, J.T. (1981). The role of inquiry in science education: Analysis and recommendations. Science Education, 65(1), 33-50.

Wellman, R.T. (1978). Science: A basic for language and reading development. In M.B. Rowe (Ed.), What research says to the science teacher: Vol. 1. Washington, DC: National Science Teachers Association.

Western Regional Environmental Education Council. (1983). Project WILD. Sacramento, CA: Western Regional Environmental Education Council.

White, E.P. (1982). Change--slow, steady, and low risk. Science and Children, 20(3), 20-21.

Willems, K.D., Willems, A.L., & Stacy, W.B. (1981). Physical and musical vibrating systems: Basic concepts. Science and Children, 18(4), 9-11.

Willet, J.B., Yamashita, J.J., & Anderson, R.D. (1983). A meta-analysis of instructional systems applied in science teaching. Journal of Research in Science Teaching, 20(5), 405-417.

Wilsey, C., & Killion, J. (1982). Making staff development programs work. Educational Leadership, 40(1), 36-38.

Wise, K.C., & Okey, J.R. (1983). A meta-analysis of the effects of various science teaching strategies on achievement. Journal of Research in Science Teaching, 20(5), 419-435.

Wolfinger, D.M. (1984). Teaching science in the elementary school: Content, process, and attitude. Toronto: Little, Brown.

Wong, H.K., & Dolmatz, M.S. (1983a). Biology: The key ideas. Englewood Cliffs, NJ: Prentice-Hall.

Wong, H.K., & Dolmatz, M.S. (1983b). Physical science: The key ideas. Englewood Cliffs, NJ: Prentice-Hall.

Wood, F.H., McQuarrie, F.O., Jr., & Thompson, S.R. (1982). Practitioners and professors agree on effective staff development practices. Educational Leadership, 40(1), 28-31.

Wood, F.H., Thompson, S.R., & Russell, F. (1981). Designing effective staff development programs. In B. Dillon-Peterson (Ed.), Staff development/organization development. Alexandria, VA: Association for Supervision and Curriculum Development.

Wright, J.D., & Hounshell, P.B. (1978). Enhancing reading through science. The Science Teacher, 45(7), 35.

Yager, R.E. (1981a). Prologue. In N.C. Harms & R.E. Yager (Eds.), What research says to the science teacher: Vol. 3. Washington, DC: National Science Teachers Association.

Yager, R.E. (1981b). What are "the basics" in general biology? The American Biology Teacher, 43(3), 154-156.

Yager, R.E. (1982). The crisis in biology education. The American Biology Teacher, 44(6), 328-336, 368.

Yager, R.E. (1983a). In defense of societal iussues as organizers for school science. School Science and Mathematics, 83(8), 651-653.

Yager, R.E. (1983b). The importance of terminology in teaching K-12 science. Journal of Research in Science Teaching, 20(6), 577-588.

Yager, R.E. (1983c). Toward new meaning of school science. Educational Leadership, 41(4), 12-18.

Yager, R.E. (1984). The major crisis in science education. School Science and Mathematics, 84(3), 189-198.

Yager, R.E. (1986). Preparing students for a technological world. Curriculum Review, 24(3), 21.

Yager, R.E., Aldridge, B.G., & Penick, J.E. (1983). Current practice: School science today. In F.K. Brown & D.P. Butts (Eds.), Science teaching: A profession speaks (1983 NSTA Yearbook). Washington, DC: National Science Teachers Association.

Yager, R.E., & Bonstetter, R.J. (1984). Student perceptions of science teachers, classes, and course content. School Science and Mathematics, 84(5), 406-414.

Yager, R.E., Bybee, R.W., Gallagher, J.J., & Renner, J.W. (1982). An analysis of the current crisis in the discipline of science education. Journal of Research in Science Teaching, 19(5), 377-395.

Yager, R.E., & Lunetta, V.N. (1984). New foci for science teacher education. Journal of Teacher Education, 35(6), 37-42.

Yager, R.E., & Penick, J.E. (1983). School science in crisis. Curriculum Review, 22(3), 67-70.

Yager, R.E., & Penick, J.E. (1984). What students say about science teaching and science teachers. Science Education, 68(2), 143-152.

Yeany, R.H. (1975). Some effects of training preservice teachers in science strategy analysis. In Abstracts of papers presented at NARST, 1975. Columbus, OH: Ohio State University, ERIC-SMEAC.

Yeany, R.H., & Miller, P.A. (1983). Effects of diagnostic/remedial instruction on science learning: A meta-analysis. Journal of Research in Science Teaching, 20(1), 19-26.

Yeany, R.H., Waugh, M.L., & Blalock, A.L. (1979). The effects of achievement diagnosis with feedback on the science achievement and attitude of university students. Journal of Research in Science Teaching, 16(5), 465-472.

Yudorf, M.G. (1984). Educational policy research and the new consensus of the 1980s. Phi Delta Kappan, 65(7), 456-459.

Zais, R.S. (1976). Curriculum: Principles and foundations. New York: Harper & Row.

Ziman, J.M. (1980). Teaching and learning about science and society. Cambridge, UK: Cambridge University Press.

APPENDIXES

Appendix 1

The Central Goal of Science Education

Because of the scientific nature of our society and the individual needs of its members, every person in order to function effectively must be *scientifically literate*. Scientific literacy must be one of the major goals of the education received by each new generation. And for those whose formal schooling has ended, ways must be found to enable them to continue to learn about the achievements and advancements of science.

Scientific literacy is the central goal for teaching science in elementary and secondary schools. Like Polaris, the North Star, which gives us a fixed point for steering a course, the goal of scientific literacy can give direction to what we do and how we do it. And science programs designed to help all our students become scientifically literate must be greatly different from those limited to preparing a selected few for careers in science.

Although the goal of scientific literacy can give direction to a science program, its components must be described before instruction can take place. Teachers must know if they are to teach about atoms, or ants, or attitudes. They also must know if factual information is to be taught by rote or thinking skills emphasized through investigative laboratory work.

What is Scientific Literacy?

National groups and individuals have made numerous attempts to define scientific literacy. The reports of several of these are cited in the references listed at the end of this chapter. A major portion of one report is reproduced as part of one of the application and analysis questions at the end of this chapter. In addition, the first Research Report, a feature that appears throughout this book, tells of two studies directed toward the formulation of a definition. Based on these reports and studies, and our own experience and thought, we believe that scientific literacy can best be defined by describing seven major components in the behavior desired of a scientifically literate person.

The scientifically literate person:

- Has knowledge of the major concepts, principles, laws, and theories of science and applies these in appropriate ways.
- Uses the processes of science in solving problems, making decisions, and other suitable ways.
- Understands the nature of science and the scientific enterprise.
- Understands the partnership of science and technology and its interaction with society.
- Has developed science-related skills that enable him or her to function effectively in careers, leisure activities, and other roles.
- Possesses attitudes and values that are in harmony with those of science and a free society.

RESEARCH REPORT

Defining Scientific Literacy

Determining the knowledge needed to read science-type stories in newspapers and magazines is one approach that has been used to define scientific literacy. Koelsche[2] at the University of Georgia found that a total of 2,999 science-related news items appeared in the twenty-two major newspapers and nine widely read magazines that were analyzed over a six-month period, extending from November, 1963 through April, 1964. One hundred and seventy-five scientific principles and 693 vocabulary words were identified that appeared one or more times in these news items. Examples of the principles identified are "All living things respond to stimuli" and "Radioactive emission involves nuclear changes."

A team composed of Pella, O'Hearn, and Gale[3] at the Scientific Literacy Research Center of the University of Wisconsin at Madison analyzed one hundred documents (books, articles in professional journals, etc.) that included one or more references to scientific literacy or closely related topics such as science and general education, and the interrelationships among science, technology, and society. It was concluded that the scientifically literate person is characterized as one with an understanding of:

1. Interrelationships of science and society (67)
2. Ethics that control the scientist in his or her work (58)
3. Nature of science (51)
4. Basic concepts in science (51)
5. Differences between science and technology (21)
6. Interrelationships of science and the humanities (21)

The numbers in the parentheses indicate the number of documents out of the one hundred analyzed that contained one or more references to that particular referent of scientific literacy.

---

[2] Charles L., Koelsche, "Scientific Literacy as Related to the Mass Media of Communication," *School Science and Mathematics*, 65 (November, 1965):719–725.

[3] Milton O. Pella, George T. O'Hearn, and Calvin W. Gale, "Scientific Literacy—Its Referents," *The Science Teacher*, 33 (May, 1966):44.

The Dimensions of Scientific Literacy

I. The scientifically literate person understands the nature of scientific knowledge.
II. The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe.
III. The scientifically literate person uses processes of science in solving problems, making decisions, and furthering his own understanding of the universe.
IV. The scientifically literate person interacts with the various aspects of his universe in a way that is consistent with the values that underlie science.
V. The scientifically literate person understands and appreciates the joint enterprise of science and technology and the interrelationships of these with each other and with other aspects of society.
VI. The scientifically literate person has developed a richer, more satisfying, and more exciting view of the universe as a result of his science education and continues to extend this education throughout his life.
VII. The scientifically literate person has developed numerous manipulative skills associated with science and technology.

Nature of Science

I. The scientifically literate person understands the nature of scientific knowledge.

Probably the only characteristic of scientific knowledge that is permanent is the nature of that knowledge as contrasted to the knowledge itself. There is no doubt that scientific knowledge, as such, is in a continuous state of change. Some scholars have concluded that not only is change in scientific knowledge inevitable but that the rate of change is increasing.
The nature of scientific knowledge is such that it is:

1. *tentative.* It is subject to change and therefore does not purport to be "truth" in an absolute and final sense. This characteristic does not diminish the value of the knowledge in the eyes of the scientifically literate person.
2. *public.* It is based on evidence that is public as opposed to personal. It is assumed that other individuals would arrive at similar conclusions when confronted with the same evidence.
3. *replicable.* It is based on evidence which, at least in theory, could be obtained by other investigators working in a different place and at a different time given similar conditions.
4. *probabilistic.* It enables probabilistic, as opposed to absolute, predictions and explanations when applied to real situations.
5. *humanistic.* It is a product of mankind resulting from an effort to impose order on nature or find patterns in nature and involves creative imagination. The knowledge itself is shaped by and from elements (i.e., concepts) that are a product of the culture.
6. *historic.* Scientific knowledge of the past has provided the basis for today's knowledge which in turn will provide the basis for tomorrow's knowledge. Science knowledge of the past should be viewed in its historical context and not be degraded on the basis of our present knowledge.

7. *unique.* Scientific knowledge is one of several "realms of meaning" or ways of knowing that man has developed. It is distinguished from other realms by virtue of the nature of its knowledge and its procedures for generating new knowledge. Conflict may occur when the same thing or event is explained by science and some other way of knowing.
8. *holistic.* Scientific knowledge produced by the various specialized sciences contributes to an overall conceptual scheme which is internally consistent. The differences among the specialized sciences are differences of degree rather than of kind.
9. *empirical.* Scientific knowledge is based ultimately on and/or derived from observation or experiment even though theory may be a useful guide to further work. It has its origin in the real world and is dependent on sense experience.

Concepts in Science

II. The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe.

There has been a persistent problem of identifying a minimal conceptual core of science knowledge ever since science courses have been established in schools. The problem has been intensified since the mid-1950s when the concept of scientific literacy became popular. To be functional, the resulting list of content items should be comprehensive without being so long as to be unwieldy.

It follows that it is not appropriate to speak of one's having attained a key concept or not. Each of these concepts represents a continuum which extends from complete naivete to increasing levels of sophistication with no upper limit. It is, therefore, appropriate to speak of an individual's level of development regarding a particular concept. Thus, a given person may have a highly developed concept of "equilibrium" but a very elementary concept of "population."

The key concepts of science are:

1. *cause-effect.* A relationship of events that substantiates the belief that "nature is not capricious." Once established, it enables predictions to be made.
2. *change.* Everything is in the process of becoming different or something else. The rate at which it happens varies from very fast to very slow so that it may be unnoticed in these extreme cases. May involve several stages or mechanisms.
3. *cycle.* The apparent pattern in which certain events or conditions seem to be repeated at regular intervals or periods.
4. *energy-matter.* Interchangeable manifestations of substance and that which enables something to be moved or changed.
5. *entropy.* An expression of the randomness, disorder, or chaos in a collection of things. Always increases in a closed system.

6. *equilibrium*. That state of affairs in which changes or tendencies to change occur in opposite directions, exist, or happen at equal rates or are of the same magnitude.
7. *evolution*. A series of slow changes that can be used to explain how something got to be the way it is or what it might become in the future. Generally regarded as going from simple to complex.
8. *field*. A region or space in which something influences or affects something else, often without direct physical contact.
9. *force*. A push or a pull.
10. *fundamental entities*. Those units which are useful in explaining certain phenomena. Units of structure and function.
11. *gradient*. A situation in which the intensity of something varies in a more or less regular pattern.
12. *interaction*. A situation in which two or more things influence or affect each other.
13. *invariance*. A characteristic of an object or a situation which stays constant even though other characteristics may change.
14. *model*. A more or less tentative scheme or structure which seems to correspond to a real structure, event, or class of events and which has explanatory value.
15. *orderliness*. The belief that there is either order in nature or that man is able to impose order on nature. Includes the various schemes or patterns that are used to express this order such as the periodic table of the elements.
16. *organism*. An open dynamic system which is characterized by the processes of life. May be used as an analog to explain certain non-life events or things.
17. *perception*. The interaction between the human mind and the external world.
18. *probability*. The relative certainty (or lack of it) that can be assigned to certain events happening in a specified time interval or sequence of other events.
19. *population*. A group of fundamental entities that have certain similarities or common characteristics.
20. *quantification*. An expression containing a numerical component resulting from measurement and associated with a concrete or abstract attribute of a thing, situation, or event.
21. *replication*. A belief that doing the same things will produce the same results if all other conditions are the same. A necessary characteristic of scientific experiments.
22. *resonance*. An action within one system which causes a similar action within another system.

23. *scale*. A consideration that other characteristics of or relationships within a system may or may not stay the same as its dimensions are increased or decreased.
24. *significance*. The belief that certain differences which exist or which follow certain actions exceed those that would be expected to be caused by chance alone.
25. *symmetry*. The belief that most, if not all, patterns in nature are structurally or functionally independent of direction.
26. *system*. A group of things or events which can be defined, at least in part, by boundaries that one person can communicate to another and which enable it to be discussed and studied more effectively.
27. *theory*. A connected and internally consistent group of sentences, equations, models, or a combination of these which serves to explain a relatively large and diverse group of things and events.
28. *time-space*. A dimension of the real world which separates things and events.
29. *validation*. A belief that similar relationships obtained by two or more different methods reflect an accurate representation of the situation being investigated.

Processes of Science

III. The scientifically literate person uses processes of science in solving problems, making decisions, and furthering his own understanding of the universe.

In recent years, the intellectual processes of science have attained the status of legitimate content for science learning. Much of this new status is due to the impetus provided by the Commission on Science Education of the American Association for the Advancement of Science (AAAS). One very persuasive argument in favor of these processes of science as basic content for science learning is that the processes are much less likely to change in time than is the traditional knowledge-based content.

The processes of science marked with "*" were designated by AAAS as "integrated processes" and were viewed as subsuming the other "basic" processes. By listing the processes alphabetically, it is intended that each process be given an "open-ended" status. That is, the basic processes are viewed as being worthy of development even after a learner has made progress with one or more of the integrated processes.

The processes of science are:

1. *classifying*. A systematic procedure used by a person to impose order on collections of objects or events.
2. *communicating*. Any one of several procedures involving various media and which carries information from one person to another.
3. *controlling variables*. Identifying and managing the factors that may in-

fluence a situation or event so that the effect of a given factor may be learned.

4. *defining operationally.* * Producing definitions of a thing or event in terms that give a physical description and/or that which results from conducting a given procedure.
5. *designing experiments.* Planning a series of data-gathering operations which will provide a basis for testing a hypothesis or answering a question.
6. *formulating models.* Devising a mechanism, scheme, or structure which will act or perform as if it were a specific real object or event.
7. *hypothesizing.* * Stating a tentative generalization that may be used to explain a relatively large number of events but which is subject to immediate or eventual testing by one or more experiments.
8. *inferring.* Explaining an observation in terms of one's previous experience.
9. *interpreting data.* * To find a pattern or other meaning inherent in a collection of data. Leads to stating a generalization.
10. *measuring.* A procedure by which one uses an instrument to estimate a quantitative value associated with some characteristic of an object or an event.
11. *observing.* The most basic process of science in which a person uses his senses to obtain information about himself or the world around him.
12. *predicting.* Predicting what future observations will be on the basis of previous information which distinguishes it from "guessing."
13. *questioning.* To raise an uncertainty, doubt, or unsettled issue which may be based on the perception of a discrepancy between what is observed and what is known by the questioner.
14. *using numbers.* The technique of using number systems to express ideas, observations, relationships, etc., often as a complement to the use of words.
15. *using space-time relationships.* The description of spatial relationships and their change with time.

Values

IV. The scientifically literate person interacts with the various aspects of his universe in a way that is consistent with the values that underlie science.

This dimension of scientific literacy is based on a definition of "value" as "a principle, standard, or quality considered worthwhile or desirable." Thus, this dimension implies that some values which many or most learners bring to school will need to be modified, even though it may be argued that schools should not seek to impress a given set of values on learners. Nevertheless, it is

impossible to imagine any scientifically literate person who does not act in a way that is consistent with these values in situations that are amenable to scientific thought and action. The more consistently the individual shows this behavior in appropriate situations, the more scientifically literate the person is.

In 1966, *Education and the Spirit of Science* was published by the National Education Association as a principal product of the Educational Policies Commission consisting of teachers, scientists, and school administrators. This book assesses the modern impact of science and technology and describes the potential value of the scientific and technological "revolution" for all people. It suggests that the "... values and associated modes of thought may in the long run be more important to mankind and to education than the visible fruits of scientific and technological pursuits."

The values that underlie science as identified in *Education and the Spirit of Science* are:

1. *longing to know and understand.* A conviction that knowledge is desirable and that inquiry directed toward its generation is a worthy investment of time and other resources.
2. *questioning of all things.* A belief that all things, including authoritarian statements and "self-evident" truths are open to question. All questions are prized although some are of greater value than others because they lead to further understanding through scientific inquiry.
3. *search for data and their meaning.* Prizing of the acquisition and ordering of data because they are the basis for theories which, in turn, are worthwhile because they can be used to explain many things and events. In some cases these data have immediate practical applications of value to mankind, as in cases in which data enables one to assess accurately the severity of a problem in society and/or the effects of policies directed to improve such situations.
4. *demand for verification.* A high regard for requests that supporting data be made public and that new empirical tests be invented and/or conducted to assess the validity or accuracy of a finding or assertion.
5. *respect for logic.* An esteem for those chains of inference that lead from raw data to conclusion according to some logical scheme and an insistence that conclusions or actions not based on such chains be subject to doubt.
6. *consideration of premises.* A prizing of frequent review of the basic external and internal assumptions from which a line of inquiry has arisen, especially when they are used as a basis for determining further action.
7. *consideration of consequence.* A belief that frequent and thoughtful review of both the direct and indirect effects resulting from pursuing a given line of inquiry or action is worthwhile and that a decision to continue or abort the inquiry or action will be made in terms of the consequences.

Science-Society

V. The scientifically literate person understands and appreciates the joint enterprise of science and technology and the interrelationships of these with each other and with other aspects of society.

The distinctions between science and technology are relatively subtle as each depends on the other for its continued pursuit. Technology is generally regarded as the application of scientific knowledge to producing real products or to the treatment of specific problems. Thus, new technology may occur either when an "old" bit of scientific knowledge is applied in a new way or when a "new" bit of scientific knowledge generates technological "spin-off."

Some of the factors involved in the interrelationships among science, technology, and other aspects of society are:

1. *science/technology.* There is a distinction between science and technology, although they often overlap and each depends on the other for continued progress. Science deals with generating and ordering conceptual knowledge. Technology deals with applying scientific knowledge to achieve full or partial solution of problem situations.
2. *variable positions.* Scientific thought and knowledge can be used to support different positions in response to specific problems (e.g., population control, water fluoridation, etc.). Thus, it is "normal" for scientists/technologists to disagree among themselves, even though they may invoke the same scientific theories and data.
3. *social influence on science/technology.* The selection of problems investigated by scientific and technological research is influenced by the needs, interests, and financial support of the larger society.
4. *ultimate value of science knowledge.* Although scientists often pursue what, on the surface, seem socially irrelevant phenomena or investigate apparently trivial phenomena, history shows a significant proportion of these studies eventually have broad application value in various and sometimes unexpected technologies. A viable bank of scientific knowledge is required to ensure the future success of technology.
5. *impact of science/technology.* Scientific and technological developments have real and direct effects on each person's life. Not all effects are desirable, nor are any effects completely free of some undesirable side-effects. In essence, there seems to be a "trade-off" principle working in which each gain is matched by one or more "losses" in terms of what has been. The "trade-off" principle involves items of knowledge, belief, and social structure as well as those of a material nature.
6. *science requires "openness."* Science thrives best when there is a free flow of questions, ideas, and results that is not restricted by personal boundaries or external authority.
7. *technology controlled by society.* Although science requires freedom to inquire if it is to function fully, applications of scientific knowledge and of technological products and practices are ultimately determined by the whole of society including scientists and technologists. These groups

have a special responsibility to inform the public and other decision makers of both the possible consequences of such applications and the need to search for such consequences.

8. *public understanding gap.* A considerable gap between scientific/technological knowledge and public understanding of it has existed in the past, continues to exist in the present, and will exist in the future. Constant effort is required by scientists, technologists, educators, and the public to minimize this gap.
9. *resources for science/technology.* The conduct of modern science and technology requires considerable resources in the form of talent, time, money, etc. Many of these resources such as that of talent require long-term preparation and allocation.
10. *limitations of science/technology.* Science/technology cannot guarantee a solution to any specific problem. In fact, ultimate solution of any problem is usually impossible, and a partial or temporary solution is all that is ever possible at a given point in time. Solutions to problems cannot be legislated, bought, or guaranteed by extreme allocation of resources. Some problems and areas of human concern are not amenable to the approaches of science/technology.
11. *scientists/technologists are human.* Scientists and technologists are "people." In fact, outside of their special field, they may not exhibit strong development of all or even most of the dimensions of scientific literacy. All people, not just an elite few, are capable of "doing" science/technology at their own level of sophistication. By the same token, vocations in some aspect of science/technology are open to practically all people.
12. *science/technology and natural resources.* Society has the ability and responsibility through science/technology to regulate environmental quality and the usage rate of natural resources to ensure a good quality of life for this and succeeding generations.
13. *science/technology and other realms.* Although there are distinctive characteristics of the knowledge and processes that characterize science/technology, there are many connections to and overlaps with the other realms of human knowledge and understanding.

Interest

VI. The scientifically literate person has developed a richer, more satisfying, and more exciting view of the universe as a result of his science education and continues to extend this education throughout his life.

This is a very personal dimension of scientific literacy and involves a general and abiding interest in science and a favorable attitude toward all aspects of science and technology. This does not mean that the scientifically literate person automatically endorses anything and everything that appears

or occurs in the name of science/technology. It does mean that the person has enthusiasm for reading, listening, watching, talking about, and getting involved in science-related things and events.

The following factors contribute to this dimension of scientific literacy:

1. *interest.* The individual feels and expresses a satisfactory level of interest in science. At the very least, the person does not "hate" science.
2. *confidence.* The individual believes he can participate in the doing of science and can understand scientific things at his own level of sophistication. He also believes he will attain a measure of self-satisfaction by doing so.
3. *media preference.* The individual chooses to become involved (reading, watching, visiting, etc.) in a significantly high proportion of science-related television programs, newspaper articles, books, public displays (e.g., museums), etc.
4. *explanation preference.* The individual shows a significant preference for scientific explanations of a given event or thing compared to non-scientific explanations for the same event or thing, assuming that the scientific explanation is at an appropriate level of sophistication.
5. *avocation.* The individual pursues, has pursued, or would like to pursue a science-related hobby such as shell collecting, photography, bird watching, etc.
6. *vocation.* The individual either is considering entering a science-related job or career or has seriously considered entering such a field.
7. *continuous learner.* The individual has gained some scientific knowledge within the very recent past no matter what age he happens to be. He frequently pursues some line of scientific inquiry of his own volition. This may take the form of enrolling in a science course which is not required by any formal program of study to which the person is committed.
8. *response preference.* The person gives a high proportion of science-based responses when questioned about events and things in an informal situation. This is especially significant when the questioner is *not* a teacher or other authority figure.
9. *"hero" perception.* The person has a relatively high esteem for the role of the scientist/technologist in today's world and acknowledges several specific scientists/technologists as having made significant contributions in the past.

Skills

VII. The scientifically literate person has developed numerous manipulative skills associated with science and technology.

The instruments and other hardware typical of science/technology seem to be a forbidding aspect of science and technology that precludes certain

individual's achievement of a high degree of scientific literacy. Many individuals are very reluctant to get involved in the active operation of unfamiliar scientific instruments or machines for one reason or another.

The list of instruments that follows is intended to represent manipulative skills important to the achievement of scientific literacy:

1. *microscope*
2. *thermometer*
3. *meter stick*
4. *balance*
5. *graduated cylinder*
6. *timing device*
7. *camera*
8. *calculator*
9. *tape recorder*
10. *computer terminal*
11. *syphgmomanometer*
12. *oscilloscope*
13. *polygraph (or some other instrument that records data as a function of time)*
14. *ammeter*
15. *pH meter (or some other electronic instrument that measures current as a function of some other physical variable)*[13]

References

Eiss, Albert F. and Mary B. Harbeck. *Behavioral Objectives in the Affective Domain.* Washington, D.C.: National Science Supervisors Association, 1969.

This book discusses the importance of objectives in the affective domain, gives examples of such objectives, and describes a means of evaluating the achievement of affective objectives.

Hurd, Paul DeHart. "Scientific Enlightenment for an Age of Science," *The Science Teacher,* January, 1970 (37, 1), pp. 13–15.

After discussing the scientific enlightenment as a point of view about the purposes for teaching science, the author identifies twelve areas of knowledge and attitude in which a scientifically enlightened person should have an operational understanding.

From Science, Students, and Schools: A Guide for the Middle and Secondary School Teacher (pp. 6, 7, 21-31) by R.D. Simpson and N.D. Anderson, 1981, New York, NY: Wiley. Copyright 1981 by John Wiley & Sons, Inc.

reader should consult Reference Section D for specific statements about the goals of schooling within provinces and territories.

The goal statements also state or imply that the schools are expected to promote the individual development of each student while providing equality of educational opportunity, although not necessarily the same type of education for all. The statements usually acknowledge the existence of variability among students. In spite of such variability, schools are expected to be responsive to the special needs of individual students and to take these into account in preparing instructional programs. Only one province, Nova Scotia, provides special documents which help teachers adjust programs for bright, slow, and handicapped learners. Other provinces may be preparing such documents, but none were available at the time this chapter was written.

Goal statements are usually written to imply that the needs of the individual and those of society are of equal importance in the outcomes of schooling. However, the additional emphasis in most documents on the need to develop special programs to meet the needs of individual students suggests that the goal of individual development takes precedence over the development of students as responsible, contributing members of society. This emphasis is usually provided in descriptive material which precedes or follows the goal statements.

Most provinces acknowledge that the goals of schooling need to be implemented somewhat differently, and will vary in importance, at each curriculum level. Nevertheless, all goals for public schools are assumed to be of equal importance in the overall program and teachers are expected to take them into account in preparing instructional programs. As one moves from elementary to upper secondary levels, however, emphasis shifts from the development of generic skills and basic knowledge to their application in specific subjects and contexts; from a focus on the local community and family unit to wider communities; from general knowledge of community services to the specific effect of these services on oneself and their relation to the wider system of services available in the larger community.

6.3.3. The Aims of Science Education

Comprehensive statements on the aims of science education, as distinct from the objectives of science courses, are provided by only two provinces, Alberta and Newfoundland. However, the aims of science education can be inferred from an analysis of science curriculum documents for specific courses and programs of study. The Science Council of Canada, as part of its review of the science curriculum, analysed both general and specific science curriculum documents and developed a summary of the aims of science education as these are reflected in the objectives of specific science courses. The analysis resulted in the development of eight categories of outcome statements (Orpwood & Souque, 1984, 62-64):

- Science content: students should know, understand and, in various ways, be able to manipulate the substance of scientific knowledge.
- Scientific skills/processes: students should develop the ability to use inquiry process skills which include observing, classifying, measuring, inferring, predicting, identifying and controlling variables, hypothesizing, experimenting, interpreting data, formulating models, and the like.
- Science and society: students should understand the role of science in the development of societies and the impact of society upon science.
- Nature of science: students should understand how the inquiry process and the formulation of knowledge works within each science discipline.
- Personal growth: students should develop such characteristics as curiosity, creativity, autonomy, self-directedness, a sense of responsibility, and so on.
- Science-related attitudes: students should develop such characteristics as intellectual honesty, open-mindedness, a willingness to investigate, a desire for accurate knowledge, and so on.
- Applied science/technology: students should understand how science is used in industry, medicine, communications, transportation, computers, household appliances, and other technological fields.
- Career opportunities: students should learn how science education can contribute to their eventual employment and to career possibilities related to science and technology.

As with the goals of schooling, all the aims of science education are viewed as important; but the emphasis among aims, and the implementation of each, varies somewhat at each curriculum level. The review by Haggarty and Hobbs (1981) of the science curricula at the elementary and secondary levels provides an excellent description of implementation differences across curriculum

From "Policies and Objectives in Science Education" (p. 139) by D. MacKeracher and D. Jantzi, 1985. In F.M. Connelly, R.K. Crocker, and H. Kass, Science Education in Canada: Vol. I, Policies, Practices, and Perceptions, Toronto; ON OISE Press. Copyright 1985 by the Ontario Institute for Studies in Education.

Appendix 3

Comparison of the 1960s Goals of Science Education With the Goals of the 1980s and Beyond

During the 1960s	During the 1980s and Beyond
1. The demand was to produce more scientists and engineers to solve perceived problems.	1. The needs are related to current social problems rooted in science and technology, e.g., depletion of energy sources, fear of nuclear energy, genetic engineering.
2. Programs were designed to meet the goals of past times in each of the science disciplines. Acquisition of knowledge was still important.	2. There is an urgent need to recognize current societal problems. The knowledge that should be considered important is that which will be useful and relevant to the solution of social problems.
3. Science was taught as a means of advancing knowledge and explanation. Science education was, therefore, preparing future scientists.	3. Science and technology are considered to be a means for improving society. Science education, therefore, should be preparing the future citizens.
4. Science and science education were oriented to the present and immediate past.	4. Science and science education must be oriented to the future in light of its potential impact in helping to resolve societal problems and concerns.
5. Science education concentrated upon the development of cognitive skills.	5. Science education must focus not only on cognitive skills, but upon affective, ethical, and aesthetic understandings as well.
6. Science was viewed as value-free, empirical science.	6. Today's science is more accurately portrayed as value-laden science in which there are moral and ethical dimensions.
7. Science demanded linear thinking and emphasized inquiry skills.	7. Science must be concerned with systemic thinking and emphasize decision-making skills.
8. The goals of science teaching were internal to the various disciplines of science.	8. The goals of science teaching are derived from the interaction of science, technology, and society.

From "Curriculum Development Projects of the 1960s" (p. 14) by W.C. Kyle, Jr., 1984. In D. Holdzkom and P.B. Lutz (Eds.), Research Within Reach: Science Education, Washington, DC: National Science Teachers Association. Copyright 1984 by the National Science Teachers Association.

Appendix 4

Likes and Prefers to:

read science books
read science magazines
read scientific articles in the newspaper
read about scientists
read about inventions
read science fiction
make collections
play science games
own science toys
own science equipment
see science TV programs
see science films
go to science fairs
go to museums
go to planetariums
go on science field trips

Does:

pursue science hobbies
experiment
plan experiments
plan original experiments
suggest plans for exploring inquiries
construct science equipment
construct science models and charts
try to invent
participate in science fairs
use correct vocabulary
try to predict what will happen on the basis of his previous learnings
observe the world around him
theorize
do independent research
avoid jumping to conclusions
seek proof
understand and use controls
talk about scientific things and events
report on scientific news
ask good science questions
detect difference between truth and fiction
persevere in methods of inquiry and research
apply his science learnings to new situations
see relationships

Believes in and Practices:

the scientific method
causal relationships
using more than one resource
repeating experiments to validate his results
questioning his results
checking his results
consulting authorities
debunking superstitions

Willing to and Does:

change his opinion if sufficient evidence warrants it
admit mistakes and try to correct them
admit he doesn't know
give credit to others when credit is due
accept the possibility of error in available resources
make allowance for human error
criticize and evaluate his own work
contribute ideas
accept responsibility
believe in scientific progress
believe in the future of science

Figure 4–6. Listing of Affecting Behavior (*Source:* Lewis and Potter, *The Teaching of Science in the Elementary School*, © 1970, p. 49. Reprinted by permission of Prentice-Hall, Inc.)

From Teaching Children Science (p. 71) by J. Abruscato, 1982, Englewood Cliffs, NJ: Prentice-Hall. Copyright 1982 by Prentice-Hall Inc.

Teacher's Evaluation List	1	2	3	4
I. *Tests*				
II. *Experiments*				
1. Is able to recognize and solve problems.				
2. Uses a variety of sources in searching for information.				
3. Makes careful observations and takes notes and records data carefully.				
4. Forms intelligent hypotheses.				
5. Is able to detect similarities and differences, discrepancies and inconsistencies.				
6. Shows open-mindedness in pursuit of solutions to problems.				
7. Is able to organize information after bringing together all data collected.				
8. Works effectively with other students.				
III. *Projects*				
1. Uses originality in planning a project.				
2. Is able to organize material.				
3. Is able to complete an activity once begun.				
4. Is aware of scientific principles involved in the chosen project.				
IV. *Scientific Interests* 1. Extends interest independently. (Home experiments, brings things for the science corner, extra readings, etc.)				
2. During discussions, is able to offer own ideas and generalize about what has been learned.				
3. Asks thoughtful questions related to the material being studied.				
V. *Comments*				

Source: Modified from materials in Robert E. Holtz, "More Than a Letter Grade." Reproduced with permission by *Science and Children* 14, no. 1 (September 1976): 23. Copyright 1976 by the National Science Teachers Association, 1742 Connecticut Avenue, N.W., Washington, D.C. 20009.

FIGURE 15–2.

tests are especially needed for low-verbal readers, as they do much better in science when given these kinds of tests. Leonard B. Finkelstein and Donald A. Hammill did a study to determine how much traditional measures of science evaluated *reading* ability, rather than science comprehension. To test this, they used the *Reading Inventory of Science Knowledge* and the *Pictorial-Aural Inventory of Science Knowledge*. The reading part of the test is a regular paper-pencil test, and the parallel form of the test is administered by projecting

From Teaching Science Through Discovery (4th ed.) (p. 282) by A.A. Carin and R.B. Sund, 1980, Toronto, ON: Merrill. Copyright 1980 by Charles E. Merrill Publishing Company.

Appendix 5

PHENOMENA	A.O. Receiving			B.O. Responding			C.O. Valuing			D.O. Organization		E.O. Characterization by a value complex	
	Awareness A1	Willingness to Receive A2	Controlled or Selected Attention A3	Acquiescence in Responding B1	Willingness to Respond B2	Satisfaction in Response B3	Acceptance of a Value C1	Preference for a Value C2	Commitment C3	Conceptualization of a Value D1	Organization of a Value System D2	Generalized Set E1	Characterization E2
1.0 Events in the natural world 1.1 Biological events 1.2 Physical events													
2.0 Activities 2.1 Informal (generally outside of school) 2.11 science activities 2.12 science-related activities 2.2 Formalized science learning activities in school													
3.0 Science 3.1 Science as a source of knowledge about the natural world 3.11 science in general 3.12 any content area in science 3.2 Science as enterprise organized to gain understanding of natural world 3.3 Science in its interrelationships with society 3.4 Scientists as people													
4.0 Inquiry 4.1 Processes of scientific inquiry 4.2 Scientific inquiry as a way of thought 4.3 Inquiry as a way of thought 4.31 in association with phenomena and problems in science 4.32 in association with phenomena and problems not in science													

Source: Leopold E. Klopfer, "A Structure for the Affective Domain in Relation to Science Education," *Science Education* 60. Reprinted by permission of John Wiley & Sons, Inc. (July-September 1976): 299–312.

NAMES OF CHILDREN										
A child										
Shows willingness to have his ideas questioned.										
Modifies his views in the face of new evidence.										
Shows a disposition not to jump to conclusions.										
Looks upon guesses and hypotheses as ideas to be tested.										
Shows respect for ideas of others.										
Seeks data and information to validate observations or explanations.										
Exhibits a healthy skepticism for generalizations not based on verifiable (repeatable) observations.										
Looks upon guesses and hypotheses as ideas to be tested.										

Source: Paul E. Blackwood and T. R. Porter, *Evaluating Science Learning in the Elementary School* (Washington, D.C.: National Science Teachers Association, 1968), p. 7.

From Teaching Science Through Discovery (4th ed.) (pp. 291-292) by A.A. Carin and R.B. Sund, 1980, Toronto, ON: Merrill. Copyright 1980 by Charles E. Merrill Publishing Company.

Appendix 6

The Schema for Classifying Educational Objectives in the Psychomotor Domain	
Perception	Sensory cues that guide action for a particular motor activity (seeing, hearing, and so on.)
Set	Preparatory adjustment or readiness for a particular kind of action or experience (mental, physical, emotional set)
Guided response	Overt behavioral act under the guidance of a teacher or in response to self-evaluation (imitation, trial and error)
Mechanism	Learned response becoming habitual
Complex overt response	Individual performing a motor act considered complex with skill, smoothly and efficiently
Adaptation	Altering motor activities to meet the demands of new problematic situations
Origination	Creating new motor skills or ways of manipulating materials out of understanding, abilities, skills

Here are some examples of educational objectives in science for the psychomotor domain:

Psychomotor Domain	*Science Example Involving Plants*
Perception	Recognition of different sizes of plants as a prerequisite to nonnumerical or numerical measurement
Set	Knowledge of bigger-than, smaller-than, inches or millimeters, and so on
Guided response	Imitation of procedures for using meter stick to measure plant growth, presented by teacher
Mechanism	Ability to measure growth of plants over a period of two weeks by himself or herself
Complex overt response	Measuring and recording daily meter-stick readings of plants on graph paper
Adaptation	Adapting the measuring skills to another aspect of plant growth, that is, measuring precisely the amount of water given at set periods

From Teaching Science Through Discovery (4th ed.) (pp. 294-295) by A.A. Carin and R.B. Sund, 1980, Toronto, ON: Merrill. Copyright 1980 by Charles E. Merrill Publishing Company.

Example of a checklist to assess psychomotor objectives

E = Excellent; A = adequate; I = inadequate

Gross body movements

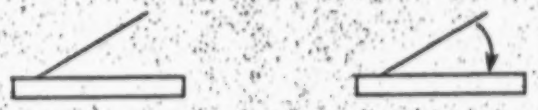
1.	Removes microscope from its case or space in the storage cabinet. Grasps the arm of the instrument with one hand and places the other hand under the base.	E	A I
2.	Sets the microscope down gently on the table with the arm toward student and stage away from student. The base should be a safe distance from the edge of the table.	E	A I
3.	Uses a piece of lens paper to wipe the lenses clean.	E	A I
4.	Clicks the lower power objective into viewing position.	E	A I
5.	Adjusts the diaphragm and mirror for the best light.	E	A I
6.	Places a prepared slide of human hair on the stage so that it is directly over the center of the stage opening.	E	A I
7.	Secures the slide in place with the stage clips.	E	A I
8.	Looks to the side of the microscope and slowly lowers the low-power objective by turning the coarse adjustment wheel until the objective almost touches the slide.	E	A I
9.	While looking through the eyepiece, with both eyes open, slowly turns the coarse adjustment so that the objective rises. The hair should become visible.	E	A I
10.	Brings the hair into sharp focus by turning the fine adjustment wheel.	E	A I
11.	Shows the properly focused slide to teacher.	E	A I
12.	Focuses the hair under high power and shows this properly focused slide to teacher.	E	A I
13.	Prepares to return microscope to storage area; turns the low power objective into viewing position and adjusts it approximately 1 cm above stage.	E	A I
14.	Returns the microscope, handling by the arm and base, to storage place.	E	A I

Finely coordinated movements

The following observations are made by the teacher who judges how well a student can prepare and stain materials for observation under a microscope.

Preparation and staining of an onion cell wet mount slide

1.	Rinses a microscope slide with water and wipes both sides with a clean soft cloth.	E	A I
2.	Rinses and dries a cover glass.	E	A I
3.	Cuts an onion lengthwise and removes a thick slice.	E	A I
4.	Peels the delicate tissue from the inner surface.	E	A I
5.	Uses a medicine dropper to place a drop of water in the center of slide.	E	A I
6.	Places a small section of onion tissue in the drop of water.	E	A I
7.	Lowers the cover glass over the onion skin:	E	A I



8.	Staining the specimen: adds a drop of iodine stain along the edge of the cover glass.	E	A I
9.	Places a small section of a paper towel on the opposite side of the cover glass. This will draw the stain across the slide by capillary action.	E	A I

From Science Instruction in Middle and Secondary Schools (p. 465) by A.T. Collette and E.L. Chiappetta, 1984, St. Louis, MO: Mosby. Copyright 1984 by Times Mirror/ Mosby College Publishing.

Appendix 7

Evaluation Techniques for Determining Student Progress in Science

Evaluation, which is a continual, ongoing process, must be clearly linked with the educational goals and objectives. The main implication of these goals and objectives for evaluation of learner achievement may be summed up in the terms *variety* and *balance*. No one or two techniques, however effective, can suffice to assess learner growth toward the attitudes, thinking processes, skills, and knowledge defined here. The techniques used in teaching toward (and evaluating attainment of) a given objective should be consistent with those used in fulfilling other educational objectives. The various techniques of evaluating student progress are as follows:

1. Observations, which can be made by teachers, students (observing other students or observing themselves), principals, parents, or other individuals, are important in evaluating progress toward objectives. Observations can be directed generally as when one is looking for evidence of learner attitudes that are revealed in spontaneous situations where the learners do not feel that they are being tested or graded. In other situations observations can be specifically directed as when one is looking for proficiency in laboratory skills, oral communication, and the like.
2. Discussions and interviews with students or parents can be valuable in evaluating progress in all four science goal areas. Tapes or notes can be helpful when the interviews and discussions are being analyzed.
3. Questionnaires, opinion surveys, and semantic differential rating scales can be used to evaluate changes in learner attitudes. Care should be taken to ensure that the learners feel free to express their true feelings; i.e., that they do not feel pressured to respond in ways they think will be more acceptable to teachers.
4. Student projects, written and oral reports, and responses to essay-type test questions can provide evidence of progress in all four goal areas. This may involve a project for a science class or the selection of a science-related topic for a paper or project in an English, art, or social studies class.
5. Performance tests can be used to evaluate manipulative skills. Evaluation may be made by the teacher, other learners, or the individual involved.
6. Objective tests are useful in diagnosing and evaluating the growth of knowledge and the use of rational thinking processes.
7. Attendance records, transfer requests, and enrollment data showing the actual number of students who avoid taking science courses can provide useful insights for evaluating student attitudes and learning experiences.

Chart

5

Evaluating the Achievement of Positive Attitudes Toward Science

Goal: ***To develop values, aspirations, and attitudes that promote the individual's personal involvement with the environment and society***

The development of positive attitudes toward science requires an integrated relationship among overall goals, specific objectives, learner behavior, teacher behaviors, and evaluations of student progress.

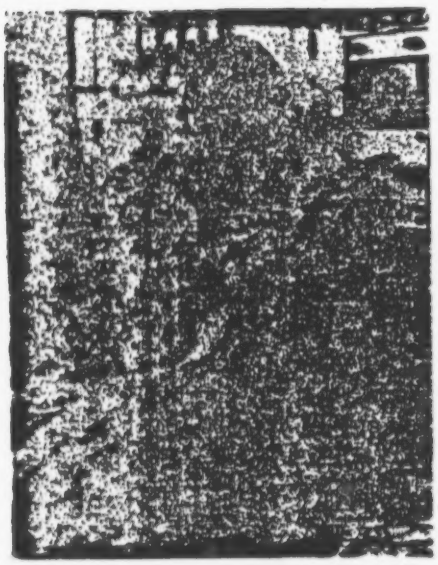
The assessment of attitudes, to be honest and effective, must be separated from the system of rewards (e.g., grades).

Terminal objectives for the attitude goal described in Chapter 3 are presented in Chart 5. Instructional ideas that can be used to achieve each objective are included on the chart, along with suggestions for evaluating learner performance.

Terminal objective
The learner:
1. Shows curiosity about objects and events.
2. Shows an awareness of and responds in a positive manner to beauty and orderliness in the environment.
3. Appreciates and respects all living organisms (including self) and their place in the environment.
4. Takes an active role in solving social problems related to science and technology.
5. Weighs alternative scientific, economic, psychological, or social factors when considering possible resolutions to problems.

Examples of teacher behaviors	Evaluation techniques (See page 61.)						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
• Demonstrates interest and pleasure when confronted with unfamiliar objects and phenomena.	X	X		X			X
• Confronts learners with objects and events in which to become interested.							
• Shares feelings of appreciation for the aesthetically pleasing (e.g., organisms, color changes, and crystal formations).	X	X	X	X			X
• Accepts and values feelings of aesthetic appreciation expressed by learners.							
• Handles living organisms carefully.	X	X	X	X	X		X
• Discusses with class the ways of minimizing environmental disruption on a field study.							
• Practices conservation of energy and materials in the classroom.	X	X	X	X			X
• Asks divergent questions aimed at increasing the learner's sensitivity to environmental problems.							
• Encourages each learner to collect data from many sources, to form opinions, and to try to influence opinions of others about community problems involving science and technology.							
• Accepts learners' opinions and values relating to socially significant problems (e.g., overpopulation and energy shortages).	X	X		X			
• Asks questions that encourage consideration of the economic impact of proposed solutions to the energy crisis.							

Chart 5 (Continued)



Terminal objective

The learner:

6. Organizes and reports the results of scientific investigations in an honest and objective manner.

7. Shows a willingness to subject data and ideas to the criticism of peers.

8. Has a critical, questioning attitude toward inferences, hypotheses, and theories.

9. Habitually applies rational and creative thinking processes when trying to find relationships among seemingly unrelated phenomena and when seeking solutions to problems.

10. Gives attention to and values science as an endeavor of human beings from all racial, ethnic, and cultural groups.

11. Considers science-related careers and makes realistic decisions about preparing for such careers, taking into account abilities, interests, and preparation required.

Examples of teacher behaviors	Evaluation techniques						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
• Does not place undue emphasis on learner's obtaining "correct" or expected results in laboratory investigations.	X	X		X	X		
• Provides opportunities for class laboratory data to be posted in a way that permits discussion of anomalous results without subjecting learners to embarrassment.							
• Accepts learner's criticisms of ideas, opinions, and interpretations advanced during a discussion.	X	X	X	X			
• Maintains an atmosphere in which learners can criticize ideas without attacking each other.							
• Accepts the learner's critical, questioning attitude toward theories, even those widely accepted by practicing scientists and even those the teacher may have come to regard as "truth."	X	X	X	X			
• Encourages students to question what they read and hear.							
• Accepts and encourages the learner's attempts to apply thinking processes to a problem, even when they lead the learner away from the "right" answer.	X	X		X			X
• Is willing to admit not understanding a discrepant event (e.g., "failure" of a demonstration); seeks explanations for what has been observed.							
• Encourages female students to consider entering fields (e.g., engineering) traditionally stereotyped as "male" activities.	X	X	X	X	X		X
• Cites advances in science and technology brought about by persons from various racial and ethnic groups.							
• Expresses admiration for persons engaged in exacting science-related work that required extensive preparation.	X	X	X	X	°		X
• Provides opportunities for learners to interact with persons engaged in science-related careers.							

Chart

6

Evaluating the Achievement of Rational and Creative Thinking Processes

Goal: ***To develop and apply rational and creative thinking processes***

Educators frequently make distinctions among attitudes, skills, content, and processes when they describe educational goals and evaluate program results. Processes are an important part of science education. When making an investigation, the learner engages in observation, measurement, classification, and other processes.

The terminal objectives for the thinking process goal presented in Chapter 3 are listed in Chart 6. Instructional ideas that can be used to achieve each objective and suggestions for measuring that achievement are included in the chart.

Terminal objective
The learner:
1. Develops ability to generate data by observing, recalling, recognizing, identifying, and measuring.
2. Develops ability to organize data by comparing, ordering, classifying, and relating.
3. Develops ability to apply and evaluate data and generate theories by hypothesizing, predicting, inferring, generalizing, theorizing, explaining, justifying, and judging.
4. Uses data-generating and theory-building processes in a cyclic manner to solve a problem; i.e., participates in scientific inquiry for the appropriate level.

Examples of teacher behaviors	Evaluation techniques (See page 61.)						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
• Makes possible a variety of laboratory investigations and field experiences.	X	X		X	X	X	
• Asks learners to report their observations; e.g., the characteristics of a rock or organism or the flight of a paper airplane.							
• Provides opportunities for learners to match oral or written descriptions with models, pictures, or specimens of the objects described.							
• Asks convergent questions to reinforce learning of important facts.							
• Confronts learners with discrepant events (e.g., owl pellets or pulse glass); encourages them to ask questions and note relationships to other phenomena.	X	X		X	X		
• Asks learners to develop schemes for ordering or classifying various objects.							
• Suggests alternative explanations for a phenomenon; asks learners to evaluate those explanations in light of available data.							
• Calls upon learners to test their hypotheses verbally and experimentally.	X	X		X		X	
• Has learners, when making a series of measurements (such as temperature versus pressure of a gas), try to predict results after the first three or four measurements are made.							
• Provides opportunities for learners to participate in research projects.							
• Asks divergent questions.							
• Following an inquiry lesson, reviews with learners a tape of the discussion, pointing out sequences of inquiry processes used.	X	X		X	X		X
• Calls upon learners to describe and evaluate the inquiry processes they use.							

Chart

7

Evaluating the Achievement of Skills in Science

Goal: ***To develop fundamental skills in the manipulation of materials and equipment; in the care and handling of living organisms; and in the collection, organization, and communication of scientific information***

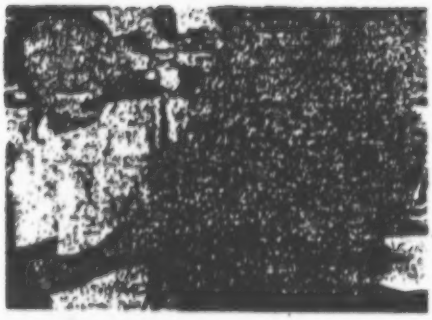
To become successful scientists and citizens of the community, learners must first develop their manipulative and communicative skills.

The terminal objectives for the skills goal presented in Chapter 3 are listed in Chart 7. Each objective is accompanied by instructional ideas and suggestions for evaluating student progress.

Terminal objective
The learner:
1. Assembles and uses laboratory apparatus, tools, and materials in a skillful manner, giving due attention to accident prevention.
2. Demonstrates proper techniques of handling and caring for living organisms.
3. Gathers the descriptive and quantitative information needed for developing or testing inferences and hypotheses by making purposeful, objective observations of things and events.
4. Gathers needed information, which has been generated by others, from a variety of sources.

Examples of teacher behaviors	Evaluation techniques (See page 61)						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
• Provides small groups of learners with appropriate materials and, without giving further direction, asks each to make an electromagnet that will pick up three paper clips.	X			X	X	X	
• Demonstrates the assembly of an electromagnet (using dry cell, wires, nails, and the like); challenges learners to make better ones.							
• Cautions learners about the hazards involved in a particular laboratory investigation; demonstrates ways to minimize them.							
• Demonstrates incorrect assembly or use of laboratory equipment, inviting the class to critique.							
• Keeps a variety of living things in the classroom.	X			X	X	X	
• Assigns, on a rotating basis, specific responsibilities for the care of living things.							
• Arranges for a resource person from a nature museum to demonstrate techniques of handling and caring for animals.							
• Provides opportunities for learners to make, record, and compare observations and measurements of organisms, chemical reactions, geologic formations, photographs, and the like.	X	X		X	X	X	
• Has learners measure the period of a pendulum, speculate about what could cause the period to change, and manipulate variables to test their hypotheses.							
• Makes a variety of reference materials of varying difficulty accessible to learners.	X	X		X	X	X	
• Arranges for learners to prepare for a tidepool field study by consulting maps, tide tables, checklists of plants and animals likely to be found, weather forecasts, and the like.							
• Helps learners develop techniques of effective reading of science textbooks and other materials. (See Appendix F.)							

Chart 7 (Continued)



Terminal objective

The learner:

5. Records observations accurately and organizes data and ideas in ways that enhance their usefulness.

6. Communicates with others (orally and in writing) in a manner that is consistent with a knowledge of scientific conventions and that facilitates the learning of the listeners or readers.

7. Uses the International System of Units (SI) metric system effectively.

8. Applies appropriate mathematical concepts and skills in interpreting data and solving problems.

Examples of teacher behaviors	Evaluation techniques						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
• Displays samples of accurate, well-organized observation records.	X			X	X	X	
• Provides histogram or graph to display results of a class laboratory investigation and facilitate discussion of variation and central tendency.							
• Has learners graph plant growth, using strips of paper cut to length of plant.							
• Provides opportunities for learners to make oral reports on their investigations and to respond to questions and comments.	X	X		X	X	X	
• Encourages learners to prepare science reports for the school newspaper or a local radio station.							
• Has learners make and calibrate their own metric measuring instruments.	X			X	X		
• Uses metric system consistently in discussing experimental results and describing objects and events.							
• Provides multiple opportunities for learners to measure and make calculations using the metric system.							
• Provides opportunities for learners to gather quantitative data and make calculations of rates, averages, densities, and the like.	X			X	X	X	
• Teaches and reinforces mathematical skills as needed by learners.							
• Provides opportunities for learners to use calculators and computers.							

Chart

8

Evaluating the Achievement of Scientific Knowledge

Goal: ***To develop knowledge of processes, facts, principles, generalizations, and applications—the products of science—and encourage their use in the interpretation of the natural environment***

Science is as much an organized body of knowledge as a system or method of discovery. It consists of both content (fact and generalizations) and method of discovery. In the classroom discoveries (content knowledge) cannot be separated from the processes of investigation. Thus, instruction must include content knowledge and the methods of obtaining that knowledge.

The terminal objectives for the knowledge goal presented in Chapter 3 are listed in Chart 8. Several instructional ideas and processes of evaluating progress are provided for each objective.

Terminal objective
The learner
1. Demonstrates knowledge of the processes of scientific inquiry.
2. Demonstrates knowledge of the content of the major scientific subdisciplines.
3. Demonstrates understanding of some basic generalizations, relationships, and principles applicable to all the sciences.
4. Demonstrates understanding of the relationship between science and society.
5. Demonstrates knowledge of science-related career opportunities and the preparation needed to pursue science-related careers.
6. Demonstrates knowledge of the contributions to science and technology made by men and women of various races and nationalities.

Examples of teacher behaviors	Evaluation strategies: No judgment						
	Observations	Interviews	Surveys	Projects/reports	Performance tests	Objective tests	Miscellaneous
The teacher							
• Accepts and models processes of scientific inquiry, encourages observing, classifying, quantifying, and hypothesizing.	X	X		X	X	X	
• Calls attention to and identifies various aspects of the inquiry process as they occur in the classroom and laboratory.							
• Asks convergent questions to reinforce learning of important facts.		X		X	X	X	
• Introduces major ideas (such as energy conservation) repeatedly in different contexts and demonstrates the broad applicability of such ideas.		X		X	X	X	
• Provides opportunities for learners to apply basic scientific principles to explain unfamiliar phenomena.							
• Encourages learners to speculate on how their lives would be different if certain scientific discoveries had not been made or had turned out differently.		X		X	X	X	
• Creates opportunities for learners to become involved in community problems involving science and technology.							
• Shows familiarity with various science-related careers.		X	X	X	X	X	
• Provides learners with information about the preparation needed for various science-related careers.							
• Gives examples of how knowledge of science can be useful in careers not normally considered "science-oriented" (e.g., law, journalism, business, sales, and building maintenance).							
• Brings to learners' attention scientific and technological contributions made by men and women of various races and nationalities.		X		X	X	X	
• Provides opportunities for the learner to interact with men and women who have made contributions to science and technology.							

Chart 8 (Continued)

Terminal objective
The learner
7. Demonstrates awareness of the relationship of science to other areas of human endeavor (e.g., art, history, and government).
8. Demonstrates knowledge of the ways in which attitudes, thinking processes, and skills can be coupled with content knowledge and used in personal decision making.

Examples of teacher behaviors	Evaluation techniques						
	Observations	Interviews	Surveys	Projects, reports	Performance tests	Objective tests	Miscellaneous
The teacher:							
•Calls upon learners to identify examples of the relationship of science to other subject areas.		X		X	X	X	
•Shows learners the ways in which knowledge of attitudes, thinking processes, and skills can be used in personal decision making. •Encourages learners to use such knowledge in making their own decisions.		X	X	X	X	X	

From Science Framework Addendum for California Public Schools, Kindergarten and Grades One Through Twelve (pp. 61-75) by California State Board of Education, 1984, Sacramento, CA: California State Board of Education. Copyright 1984 by the California State Board of Education.

Appendix 8

Guidelines for evaluation of a science program

The Appropriateness of Course Content and Curriculum

How Effective Is Your School in Providing For Each of the Following:	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
1 Having the program planners examine a wide variety of curriculum guides, textbooks, and other materials as part of the process of curriculum planning?				
2 Ensuring that the information in science textbooks and materials is valid, accurate, and up-to-date?				
3 Making certain that the course content being learned by students is consistent with the basic goals of the *Science Framework for California Public Schools*: attainment of positive attitudes toward science; attainment of manipulative and communicative skills in science; and attainment of scientific knowledge?				
4 Keeping teachers informed about new materials and significant new developments in science?				
5 Establishing at the elementary level a balance of instruction in life science, earth science, and physical science?				
6 Offering at the secondary level a wide variety of courses each year, including advanced courses, general courses, and minicourses in specialized areas of science?				
7 Ensuring that the sequence of the curriculum reflects students' general orientation to the world around them?				

Teaching Methods

How Effective Is Your School in Providing For Each of the Following:	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
1 Encouraging teachers of science to use a variety of teaching methods, such as demonstrations, group experiments, modeling, discussion, multimedia instruction, individual investigation or research, student tutoring, and questioning?				
2 Encouraging teachers to modify their teaching methods to take into account the needs, strengths, and interests of individual students or groups?				
3 Permitting high school students to choose among classes and teachers that offer a variety of instructional methods and teaching styles?				
4 Encouraging teachers to modify their teaching methods when evaluation data or direct observation indicate that these methods are not successful?				
5 Assessing student learning regularly through quizzes, tests, examinations, and reports?				

Teaching Methods, *continued*

How Effective is Your School in Providing For Each of the Following:	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
6 Checking students continually to determine whether they are understanding what is being taught?				

Sustaining Student Involvement and Motivation in Science

How Effective is Your School in Providing For Each of the Following:	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
1 Allowing time in classes for open discussion of science and related topics so that students feel free to ask questions?				
2 Encouraging teachers to modify lessons, when necessary or appropriate, to take students' needs and interests into account?				
3 Giving students opportunities to initiate scientific investigations and explorations in areas of special interest?				
4 Translating current events into interesting science activities?				
5 Encouraging students to explore science-related issues and to test hypotheses?				
6 Securing an adequate number of science materials for students who have limited proficiency in English and making certain that teachers use these materials sensitively and adequately?				
7 Ensuring that students who have limited proficiency in English are as involved in science classes as students who are fluent in English and that they are learning the same concepts as those which students who are fluent in English are learning?				
8 Giving handicapped students adequate opportunities to participate in science classes and providing handicapped students with adequate opportunities and special learning materials to become actively involved in laboratory activities? Ensuring that handicapped students are learning the same concepts that nonhandicapped students are learning?				
9 Giving gifted and talented students adequate opportunities to pursue science projects and interests in science independently, in groups, and in tutorials with teachers, older students, and volunteers?				
10 Providing science-oriented extracurricular activities and making students aware, on a regular basis, of such activities?				
11 Involving the staff of special programs (e.g., special education teachers, bilingual education teachers) in the planning of the science education program?				

The Amount and Quality of Time Spent on Science Education *How Effective is Your School in Providing For Each of the Following:*	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
1 Allocating a specific amount of time for science education for each student during each school week and making that a provision of the school-level plan?				
2 Encouraging students to become positively and actively involved in science classes?				
3 Varying science activities sufficiently to allow different kinds of student participation and engagement; e.g., combination of lectures, laboratory activities, discussions, small group activities, and field studies?				
4 Encouraging teachers to make homework assignments that review and reinforce concepts learned in class and letting students know they are expected to complete the assignments?				
5 Requesting that students complete reading assignments before class time?				
6 Contacting parents when students fail to complete homework assignments on time?				
7 Having well-known and uniformly applied consequences for not completing the homework assignments on time?				
8 Training parents to supervise and assist their children with homework?				

Standards and Expectations *How Effective is Your School in Providing For Each of the Following:*	*Ineffective*	*Somewhat Effective*	*Effective*	*Very Effective*
1 Adopting schoolwide standards for homework, academic performance, classroom behavior, workmanship, and so forth, which are included in the written plan?				
2 Making students and parents aware of the adopted standards and the consequences for not meeting them?				
3 Applying the standards uniformly?				
4 Encouraging teachers, students, and parents to regard academic achievement as a highly positive attribute?				
5 Encouraging students to finish homework on time?				
6 Making certain that teachers and students are on time and ready to begin work when class begins?				
7 Making students and parents aware of the amount and quality of academic work necessary to receive a specified grade?				
8 Making students and parents aware of the standards of thoroughness, neatness, care, and precision expected of students' work?				

From Science and Society: A Source Book for Elementary and Junior High School Teachers (pp. 222-224) by R. Peterson et al., 1984, Columbus, OH: Merrill. Copyright 1984 by Charles E. Merrill Publishing Company.

Appendix 9

The following statements are descriptions of various facets of science teaching. Read each of the statements carefully. Using the scale given below, indicate how each statement presently characterizes you as a future science teacher.

5–Very characteristic of me. This is a real strength of my future teaching.
4–Frequently characteristic of me. This is a good aspect of my science teaching.
3–Sometimes characteristic of me. I should evaluate this aspect of my science teaching.
2–Seldom characteristic of me. I should improve this aspect of my science teaching.
1–Never characteristic of me. I really need to improve.

As a science teacher I:

____ 1. Am well read in science.
____ 2. Have a well-organized science course.
____ 3. Adjust my teaching to the class situation.
____ 4. Have a good rapport with my science students.
____ 5. Enjoy teaching science to students.
____ 6. Have a thorough knowledge of science.
____ 7. Always plan and prepare for science class.
____ 8. Use a variety of techniques in teaching science.
____ 9. Recognize the unique needs of my science students.
____10. Am enthusiastic about teaching science.
____11. Present science concepts that are current and relevant.
____12. Recognize the need to modify daily and unit plans.
____13. Facilitate different types of student activities in science.
____14. Relate well with students on the individual and group levels.
____15. Get excited when students learn science.
____16. Am well informed in science-related fields.
____17. Have thought about the long-range goals of my science class.
____18. Use different curriculum materials and instructional approaches to teach science.
____19. Am sincere while helping my science students.
____20. Make an extra effort to help students learn science.
____21. Am aware of science-related social issues.
____22. Have a continuity of course material in science.
____23. Provide adequate opportunity for active work by science students.
____24. Listen to student questions and ideas.
____25. Am excited and energetic when teaching science.

Now go back and add up your responses for the groups of questions listed in the left column. Divide the total number of points by 5. The result should be a number between 1 and 5 for each of the categories listed. Refer back to the 5-point scale for your evaluation.

Questions		Average Score	Category
1, 6, 11, 16, 21	=	_____	Knowledge of science
2, 7, 12, 17, 22	=	_____	Planning and organization
3, 8, 13, 18, 23	=	_____	Teaching methods
4, 9, 14, 19, 24	=	_____	Personal relations
5, 10, 15, 20 + 25	=	_____	Enthusiasm

Scientific Knowledge

There are a number of relatively easy ways to update and keep abreast of scientific developments.

- ☐ Read the science content chapters of this book on Environmental Biology, Health Sciences, Earth and Space Sciences, and Physical Sciences.
- ☐ Read an introductory textbook in the area you feel needs improvement.
- ☐ Enroll in science courses at a local college or university.
- ☐ Contact the district or state science supervisor and see if a workshop can be organized.
- ☐ Subscribe to a magazine such as *Science '84* (title reflects current year)
- ☐ Read *Scientific American*, or purchase offprints of articles or monographs of accumulated articles on important topics.
- ☐ Join the National Science Teachers Association (NSTA) and read one of their journals, *Science and Children*, *The Science Teacher*, or *Journal of College Science Teaching*.
- ☐ Subscribe to and read *Science News*.
- ☐ Attend local, state, regional, or national conventions of scientific societies and academies of science, science teachers, and teachers.
- ☐ Make a point of watching television programs on scientific issues. (NOVA is a science program sponsored by the National Science Foundation and is shown on the Public Broadcasting System.)
- ☐ Read the science sections of weekly magazines such as *Time* or *Newsweek*.
- ☐ Go to local museums and planetariums.

Planning and Organization

If this is a concern, part of the problem can be addressed through better lesson planning and classroom organization.

- ☐ Reread chapter 5, "Planning to Teach," and other chapters on planning in various teaching methods' handbooks.
- ☐ Find a colleague who seems to be well-organized and ask if the two of you could spend some time planning classes together.
- ☐ Ask the science supervisor to look over your science program and suggest ways to improve the organization.
- ☐ Have a colleague observe your teaching and make suggestions concerning your lesson plans and class management.

Teaching Methods

Teachers often find it difficult to break old habits and try new teaching methods, but you can do it. Here are some suggestions.

- ☐ Reread chapter 4, "Taxonomy of Common Teaching Methods" and try several new methods.
- ☐ Look over journals such as *Science and Children*, *The Science Teacher*, and *The American Biology Teacher* for new approaches to science teaching.
- ☐ Take a professional day and observe several science teachers who use methods that you are interested in adopting.
- ☐ Read *Models of Teaching* by Bruce Joyce and Marsha Weil. This is an excellent book that presents different teaching methods.
- ☐ **Team teach** with another science teacher who uses different teaching methods.
- ☐ Request a visit from the science supervisor for new and different approaches to science teaching.

Interpersonal Relations

This is an area that is essential to effective science teaching, yet often neglected in the education of science teachers. (Sources may be found in the Bibliography at the end of this chapter.)

- ☐ Read *Personalizing Science Teaching* by Rodger Bybee.
- ☐ Contact the Association for Humanistic Psychology (325 North Street, San Francisco, California, 92549) and ask for information on workshops, seminars, and meetings in your region.
- ☐ Read *Reaching Out: Interpersonal Effectiveness and Self-Actualization* by David Johnson.
- ☐ Read *Teacher Effectiveness Training* by Thomas Gordon.
- ☐ Read *The Skills of Teaching: Interpersonal Skills* by Robert Carkhuff et al.
- ☐ Read *Creative Questioning and Sensitive Listening: A Self-Concept Approach* by Robert Sund and Arthur Carin.
- ☐ Read and complete the exercises in "You've Got to Reach Them to Teach Them" by Anita Simon and Claudia Gyram.
- ☐ Read *Human Relations and Your Career: A Guide to Interpersonal Skills* by David Johnson.

Personal Enthusiasm

If you lack enthusiasm for teaching science, the problem is difficult but not impossible to resolve. The reason for the difficulty is that the problem involves a personal dimension of your teaching. We can recommend an introspective route to improvement.

- ☐ Think about your original interest and excitement in science and teaching. What made you choose teaching? Now, think about what you know about yourself and teaching science. What is lacking? Where did the spark of enthusiasm go?
- ☐ List your frustrations about teaching. What are the problems you have encountered as a science teacher? What caused you to **"burn out"** or to change your interest in science teaching?
- ☐ Attend meetings of science teachers such as NSTA. This can often inspire enthusiasm through new ideas and new colleagues.
- ☐ Form a group to improve teaching in your school. You will probably find others who share your problem and the discussion and support can certainly assist you to develop new enthusiasm for teaching.
- ☐ Take a professional day and visit other science teachers who are dynamic and enthusiastic.

From Science and Society: A Source Book for Elementary and Junior High School Teachers (pp. 237-239) by R. Peterson et al., 1984, Columbus, OH: Merrill. Copyright 1984 by Charles E. Merrill Publishing Company.

Example of a questionnaire to assess teacher effectiveness

The following statements concern the science teacher and what is happening during science lessons. Circle the appropriate number following each statement based on the scale below:

1. Almost always
2. Frequently
3. Sometimes
4. Once in a while
5. Not at all

Circle only one number for each statement. Example:

Science lessons are well organized. 1 2 3 4 (5)

By circling number five, you believe that your science teacher does not have well-organized science lessons at any time. If you circled number one, you believe that your science teacher almost always has well-organized science lessons.

1. The teacher is interested in students. 1 2 3 4 5
2. The teacher knows the subject matter well. 1 2 3 4 5
3. The teacher is enthusiastic about the subject. 1 2 3 4 5
4. The teacher uses several types of activities during a class period. 1 2 3 4 5
5. The teacher often uses films, slides, and filmstrips with science lessons. 1 2 3 4 5
6. The teacher uses examples from everyday living whenever possible. 1 2 3 4 5
7. The teacher uses familiar objects to teach science lessons. 1 2 3 4 5
8. Lessons are well prepared and organized. 1 2 3 4 5
9. The teacher makes the objectives of a lesson clear. 1 2 3 4 5
10. The lessons are presented so that they are interesting. 1 2 3 4 5
11. The teacher makes the students think. 1 2 3 4 5
12. The teacher can explain concepts and principles so that they can be understood. 1 2 3 4 5
13. The teacher asks good questions. 1 2 3 4 5
14. The teacher makes good use of class participation. 1 2 3 4 5
15. The teacher uses the chalkboard frequently and writes all scientific words on the board as they are used. 1 2 3 4 5
16. The teacher gives the students a chance to do projects outside the classroom. 1 2 3 4 5
17. The teacher makes good and interesting homework assignments. 1 2 3 4 5
18. The teacher writes good, clear tests. 1 2 3 4 5
19. The tests are fair. 1 2 3 4 5
20. The teacher uses the tests to help the students learn. 1 2 3 4 5
21. The teacher is available for extra help. 1 2 3 4 5
22. The laboratory is well organized. 1 2 3 4 5
23. The laboratory exercises are stimulating and interesting. 1 2 3 4 5
24. The laboratory exercises make students think. 1 2 3 4 5
25. The laboratory gives students a chance to ask questions and experiment. 1 2 3 4 5
26. The students usually give full attention to what is taking place in the science class. 1 2 3 4 5
27. The science class is usually exciting. 1 2 3 4 5
28. The students in the class are generally interested in what is being taught. 1 2 3 4 5
29. The science textbook for the course is written so that I can understand it.

Example of a questionnaire to assess teacher effectiveness—cont'd

30. The science subject is interesting.	1	2	3	4	5
31. The teacher has a good voice and does not speak in a monotone.	1	2	3	4	5
32. The teachers and students in the class get along well.	1	2	3	4	5
33. The teacher is well liked by students in the class.	1	2	3	4	5
34. The teacher has good discipline.	1	2	3	4	5

The above questionnaire can be modified by adding the items below to make it useful for science supervisors to rate the science teachers. It would also be useful for self-evaluation.

1. The science teacher works well with other teachers.	1	2	3	4	5
2. The science teacher is involved with the total science program and not just the course he or she teaches.	1	2	3	4	5
3. The science teacher is concerned about the science curriculum and works with other teachers to improve it.	1	2	3	4	5
4. The science teacher is very professional and attends professional meetings.	1	2	3	4	5
5. The science teacher helps bring the community's attention to the school's science program.	1	2	3	4	5
6. The science teacher is a member of one or more professional organizations for science teachers.	1	2	3	4	5
7. The science teacher is involved in committee work associated with science curriculum improvement.	1	2	3	4	5
8. The science teacher reads professional journals, scientific publications, and current books on science to keep up-to-date.	1	2	3	4	5
9. The science teacher keeps up-to-date on new approaches to teach science, curriculum, teaching resources, and teaching aids.	1	2	3	4	5

From Science Instruction in Middle and Secondary Schools (pp. 467-468) by A.T. Collette and E.L. Chiappetta, 1984, St. Louis, MO: Mosby. Copyright 1984 by Times Mirror/Mosby College Publishing.

Appendix 10

Teachers in high quality programs regularly reinforce the educational links between ho . and school by providing parents with information about science education opportunities that they and their children can share.

Questions for Determining Whether or Not You Are Giving Adequate Attention to the Use of Resources in the School and Community

1. Do teachers regularly develop or acquire free or inexpensive materials to supplement existing classroom kits and laboratory materials?
2. Do students visit local science museums and other science-related institutions, and do staff members of these institutions make presentations to students at school?
3. Do students take field trips to natural outdoor settings, assisted by local conservation and wildlife organizations?
4. Do students have opportunities to learn about scientific and technological advances being made or employed by local businesses and industries?
5. Do teachers of science help parents to initiate and lead activities outside of school in which the entire family can be involved; i.e., by providing parents with science work sheets and guides?
6. Are commercially sponsored materials carefully screened to make sure that information about science and technology will be presented in an accurate, nonbiased manner?

Teachers in high quality science programs encourage parents to take their children to zoos, museums, and planetariums.

Checklist

All of the questions asked throughout this publication have been compiled into the checklist on the following pages. The checklist was designed to be used in the process of conducting an actual on-site assessment of a school's science program. It is important, however, that readers familiarize themselves first with the contents of the preceding chapters. The information in those chapters provides suggestions and specific recommendations to make the checklist meaningful and ultimately useful.

School-Level Planning for a High Quality Science Education Program

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Developing a school-level plan for a high quality science education program and making it readily available in written form?	___	___	___	___
2 Making the plan consistent with local school district policies?	___	___	___	___
3 Making certain that each teacher in the school is aware of his or her role in implementing the plan and giving each one an opportunity to participate in developing or modifying the plan if he or she wishes?	___	___	___	___
4 Ensuring that the *Science Framework for California Public Schools* and the county superintendents' *Course of Study* are used by those designing the school-level plan?	___	___	___	___
5 Developing a plan that contains realistic, attainable goals and objectives based on assessed needs?	___	___	___	___
6 Adopting goals and objectives that reflect new scientific and technological developments with which students will need to be acquainted?	___	___	___	___
7 Holding regular meetings in which administrators, teachers, parents, students, and others involved in implementing the school-level plan discuss modifications in the plan, ways of implementing it, and ways of evaluating its success?	___	___	___	___
8 Making science textbooks and related materials available to all students?	___	___	___	___
9 Having enough textbooks available so that students can take them home?	___	___	___	___
10 Developing a physical setting of classrooms and a school environment, in general, that supports science education?	___	___	___	___

School-Level Planning for a High Quality Science Education Program

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
11 Involving all the students in some aspect of science education?				
12 Making science classes available to students throughout the school year?				
13 Making information about the science education program available to parents on a regular basis?				
14 Developing a plan that clearly provides for the allocation of resources (staff, rooms, materials, financial support) for the science education program?				
15 Identifying at least one person in the school clearly identified as having a leadership role for science education?				
16 Making the science education plan an integral part of other school plans, such as the ones for school improvement and compensatory education?				

Consistency and Articulation in Your Science Education Program

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Ensuring that the content of the science education program is clearly documented in a curriculum guide?				
2 Ensuring that all students will receive instruction in the basic content areas of science and that the instruction will be appropriate to their respective grade levels?				
3 Ensuring that the curriculum guide is being implemented consistently and uniformly schoolwide, i.e., appropriate textbooks and materials are being used at the grade levels for which they were designated, and students are regularly assessed to determine whether or not they are acquiring the values, skills, and knowledge specified in the curriculum guide?				
4 Holding regular meetings of staff members and other school-level planners to discuss the consistency and sequence of the curriculum and to make modifications that will continue to support the basic sequential design?				

Consistency and Articulation in Your Science Education Program

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
5 Developing procedures for school staff and program planners to follow in order to maintain consistency and articulation among science classes?				
6 Ensuring that students study science in every grade from kindergarten through grade twelve, following an agreed-upon sequential plan?				
7 Providing for all high school students to enroll in at least one science course each year?				
8 Providing help for students who enter the program midyear and who have not covered portions of the curriculum?				

Standards and Expectations

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Adopting schoolwide standards for homework, academic performance, classroom behavior, workmanship, and so forth, which are included in the written plan?				
2 Making students and parents aware of the adopted standards and the consequences for not meeting them?				
3 Applying the standards uniformly?				
4 Encouraging teachers, students, and parents to regard academic achievement as a highly positive attribute?				
5 Encouraging students to complete homework on time?				
6 Making certain that teachers and students are on time and prepared to begin work when class begins?				
7 Making students and parents aware of the amount and quality of academic work necessary to receive a specified grade?				
8 Making students and parents aware of the standards of thoroughness, neatness, care, and precision expected of students' work?				

The Amount and Quality of Time Spent on Science Education

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Allocating a specific amount of time for science education for each student during each school week and making that a provision of the school-level plan?				
2 Encouraging students to become positively and actively involved in science classes?				
3 Varying science activities sufficiently to allow different kinds of student participation and engagement, e.g., combination of lectures, laboratory activities, discussions, small group activities, and field studies?				
4 Encouraging teachers to make homework assignments that review and reinforce concepts learned in class and letting students know they are expected to complete the assignments?				
5 Requesting that students complete reading assignments before class time?				
6 Contacting parents when students fail to complete homework assignments on time?				
7 Having well-known and uniformly applied consequences for not completing the homework assignments on time?				
8 Training parents to supervise and assist their children with homework?				

Coordinating Science with Other Curriculum Areas

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Encouraging teachers to use science content regularly in the teaching of reading, writing, mathematics, social studies, art, and other areas?				
2 Displaying written essays, reports, poetry, and art projects that incorporate science-related content?				
3 Having students keep journals describing what they have learned in science classes or noting the progress of experiments?				

Coordinating Science with Other Curriculum Areas

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
4 Holding regular meetings of the school staff, parents, and science specialists to discuss ways of coordinating science with other areas of the curriculum?				
5 Having the various departments at the secondary level meet to discuss ways of coordinating science education with other disciplines; i.e., using science as a tool for teaching writing or art?				
6 Encouraging and giving opportunities to teachers to participate on interdisciplinary teams that allow for a variety of approaches to teaching science and other subjects?				

Provisions for Financial Support

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Having the school administration make a commitment to continuous financial support of science education by providing for it in the school budget?				
2 Adopting a budget that provides for a balance of program components, such as materials and staff development?				
3 Making funds for consumable or perishable materials readily accessible to teachers?				
4 Investigating a variety of funding sources for science education, including school improvement, compensatory education, and other state and federal programs?				

The Appropriateness of Course Content and Curriculum

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Having the program planners examine a wide variety of curriculum guides, textbooks, and other materials as part of the process of curriculum planning?				
2 Ensuring that the information in science textbooks and materials is valid, accurate, and up-to-date?				

The Appropriateness of Course Content and Curriculum

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
3 Making certain that the course content being learned by students is consistent with the basic goals of the *Science Framework for California Public Schools* attainment of positive attitudes toward science, attainment of manipulative and communicative skills in science, and attainment of scientific knowledge?				
4 Keeping teachers informed about new materials and significant new developments in science?				
5 Establishing at the elementary level a balance of instruction in life science, earth science, and physical science?				
6 Offering at the secondary level a wide variety of courses each year, including advanced courses, general courses, and minicourses in specialized areas of science?				
7 Ensuring that the sequence of the curriculum reflects students' general orientation to the world around them?				

Teaching Methods

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Encouraging teachers of science to use a variety of teaching methods, such as demonstrations, group experiments, modeling, discussion, multimedia instruction, individual investigation or research, student tutoring, and questioning?				
2 Encouraging teachers to modify their teaching methods to take into account the needs, strengths, and interests of individual students or groups?				
3 Permitting high school students to choose among classes and teachers that offer a variety of instructional methods and teaching styles?				
4 Encouraging teachers to modify their teaching methods when evaluation data or direct observation indicate that these methods are not successful?				
5 Assessing student learning regularly through quizzes, tests, examinations, and reports?				
6 Checking students continually to determine whether they are understanding what is being taught?				

Creating an Effective Balance Between the Use of Laboratory Materials and Written Materials

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Encouraging science teachers to use laboratory and other hands-on materials in conjunction with written materials, such as textbooks, activity cards, work sheets, curriculum guides, and students' written reports or stories?	___	___	___	___
2 Refurbishing or replenishing science materials on a regular basis?	___	___	___	___
3 Encouraging students who have successfully completed laboratory experiments to look for additional insights by referring them to books, periodicals, and other written materials?	___	___	___	___
4 Making materials for science education readily available to all teachers who want and need them?	___	___	___	___
5 Using written materials as both an introduction to laboratory experiments and as a follow up to the experiments?	___	___	___	___
6 Having teachers give attention to inventory, ordering, storage, safety, and disposal of materials?	___	___	___	___

Sustaining Student Involvement and Motivation in Science

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Allowing time in classes for open discussion of science and related topics so that students feel free to ask questions?	___	___	___	___
2 Encouraging teachers to modify lessons, when necessary or appropriate, to take students' needs and interests into account?	___	___	___	___
3 Giving students opportunities to initiate scientific investigations and explorations in areas of special interest?	___	___	___	___
4 Translating current events into interesting science activities?	___	___	___	___
5 Encouraging students to explore science-related issues and to test hypotheses?	___	___	___	___

Sustaining Student Involvement and Motivation in Science

How effective is your school in providing for each of the following:		Ineffective	Somewhat effective	Effective	Very effective
6	Securing an adequate number of science materials for students who have limited proficiency in English and making certain that teachers use these materials sensitively and adequately?	___	___	___	___
7	Ensuring that students who have limited proficiency in English are as involved in science classes as students who are fluent in English and that they are learning the same concepts as those which students who are fluent in English are learning?	___	___	___	___
8	Giving handicapped students adequate opportunities to participate in science classes and providing handicapped students with adequate opportunities and special learning materials to become actively involved in laboratory activities? Ensuring that handicapped students are learning the same concepts that nonhandicapped students are learning?	___	___	___	___
9	Giving gifted and talented students adequate opportunities to pursue science projects and interests in science independently, in groups, and in tutorials with teachers, older students, and volunteers?	___	___	___	___
10	Providing science-oriented extracurricular activities and making students aware, on a regular basis, of such activities?	___	___	___	___
11	Involving the staff of special programs (e.g., special education teachers, bilingual education teachers) in the planning of the science education program?	___	___	___	___

Careers in Science and Science-Related Fields

How effective is your school in providing for each of the following:		Ineffective	Somewhat effective	Effective	Very effective
1	Giving students at all grade levels and ability levels opportunities to meet and talk with people in science-related fields, both in school and in their job settings; to learn what they do; and to explore long-range career goals?	___	___	___	___
2	Making students aware of the need to maintain career options by taking as many mathematics and science courses as possible?	___	___	___	___

Careers in Science and Science-Related Fields

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
3 Providing students regularly with information about science-oriented job opportunities for teenagers and entry-level positions in science-related occupations that may not require advanced science courses?	___	___	___	___
4 Advising students of the requirements and recommendations for admission to specific college programs involving science?	___	___	___	___
5 Offering courses and other opportunities for noncollege-bound students to pursue science-related careers?	___	___	___	___
6 Ensuring that school counselors are aware of and informed about science-related career options?	___	___	___	___
7 Making information about science-oriented careers available and offering career counseling to students who request it?	___	___	___	___
8 Letting students know where they can obtain counseling relevant to science-oriented careers?	___	___	___	___
9 Encouraging graduates of the school to visit the school regularly to offer students information and counseling regarding science-oriented careers?	___	___	___	___
10 Having the school's science teachers assist the guidance department in acquiring and maintaining current and reliable information about science-oriented careers for counselees?	___	___	___	___

Staffing and Staff Development

How effective is your school in providing for each of the following:	Ineffective	Somewhat effective	Effective	Very effective
1 Assigning those teachers who are most interested and skilled in science responsibility for teaching science?	___	___	___	___
2 Making supplemental staffing available through the use of aides, resource people, specialists, volunteers, interns, and visiting teachers from co.nmunity agencies, science centers and museums, and colleges and universities?	___	___	___	___

Staffing and Staff Development

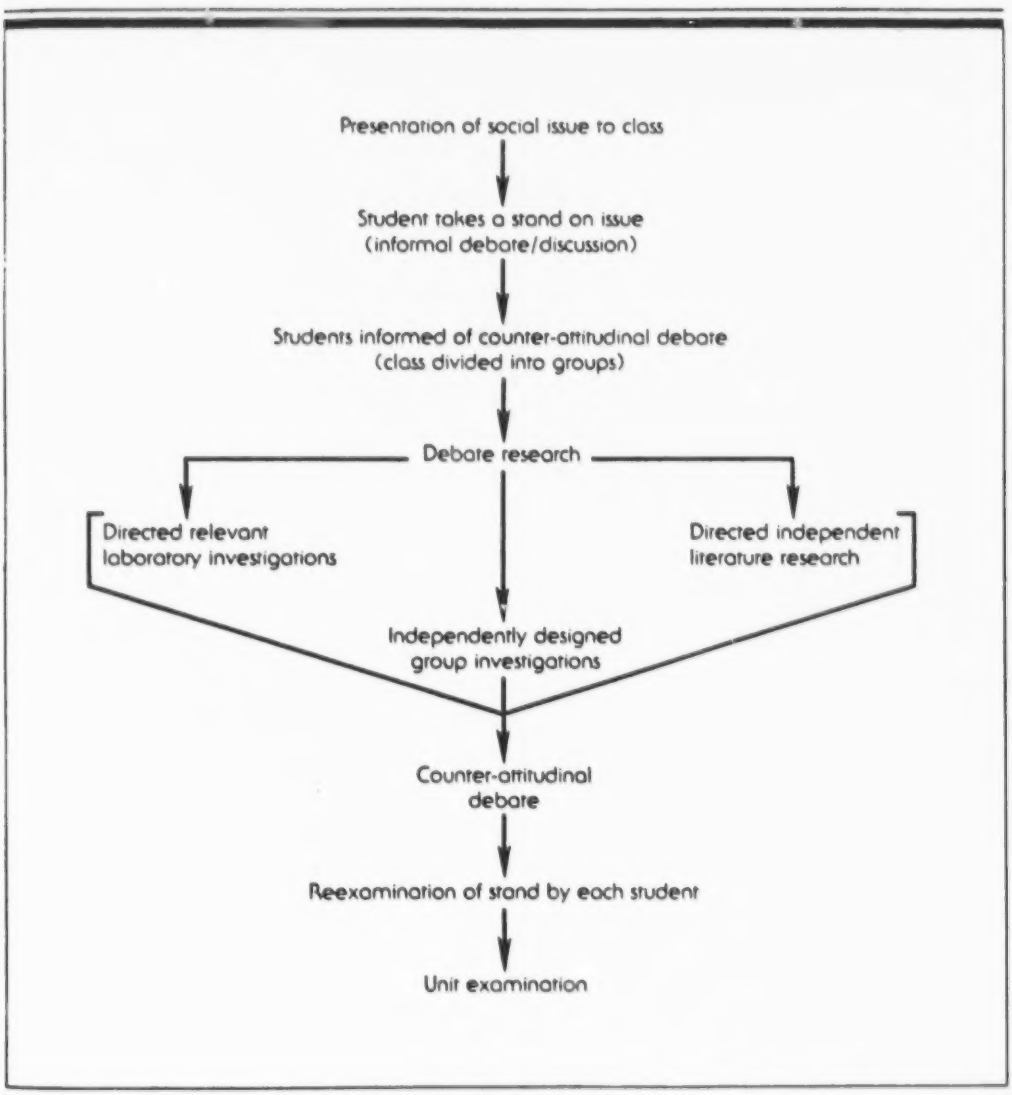
How effective is your school in providing for each of the following:				
		Ineffective	Somewhat effective	Effective	Very effective
3	Involving parents and others in the community who are knowledgeable or experienced in particular aspects of science in planning and implementing the program?	___	___	___	___
4	Having school staff members assist in designing staff development programs based on clearly identified needs?	___	___	___	___
5	Making the staff development program consistent with the school's planned program for science education?	___	___	___	___
6	Continuing the staff development program over an extended period of time and allowing for training, skill development, classroom observation, additional follow-up and coaching?	___	___	___	___
7	Scheduling staff development sessions so that teachers can participate with a minimum of fatigue, disrupted schedules, and loss of time in the classroom?	___	___	___	___
8	Giving teachers opportunities to practice new skills that they are learning or to experiment with new materials before trying them out in the classroom?	___	___	___	___
9	Offering a staff development program that helps teachers gain specific skills and techniques and secure materials that can be immediately useful to them?	___	___	___	___
10	Offering a staff development program that provides training for science teachers in how to teach the basic skills of reading, writing, and computation in secondary science classes?	___	___	___	___
11	Establishing a professional library with science materials so that teachers are continually able to come in contact with new ideas and developments in the field? Encouraging teachers to use this library regularly?	___	___	___	___
12	Developing a staff development program that provides for such important aspects of a high quality science program as the renewal and updating of information about scientific developments; research relevant to science education; and ways of coordinating science education with instruction in other disciplines?	___	___	___	___
13	Encouraging teachers to participate in professional organizations, meetings, and conferences in order to upgrade their skills in science education?	___	___	___	___
14	Supporting teacher in-service training programs?	___	___	___	___

The Use of Resources in the School and Community

How effective is your school in providing for each of the following:				
1 Encouraging teachers to develop or to acquire free or inexpensive materials to supplement existing classroom kits and laboratory materials?	___	___	___	___
2 Scheduling visits to local science museums and other science-related institutions and inviting staff members of these institutions to make presentations to students at school?	___	___	___	___
3 Scheduling field trips to natural outdoor settings with the help of local conservation and wildlife organizations?	___	___	___	___
4 Giving students opportunities to learn about scientific and technological advances being made or employed by local businesses and industries?	___	___	___	___
5 Helping parents initiate and lead activities outside of school in which the entire family can be involved; e.g., by providing parents with science work sheets and guides?	___	___	___	___
6 Screening commercially sponsored materials to make sure that information about science and technology is presented in an accurate, nonbiased manner?	___	___	___	___

From Science Education for the 1980s: A Planning and Assessment Handbook for Kindergarten Through Grade Twelve (pp. 31-42) by California State Board of Education, 1982, Sacramento, CA: California State Board of Education. Copyright 1982 by the California State Board of Education.

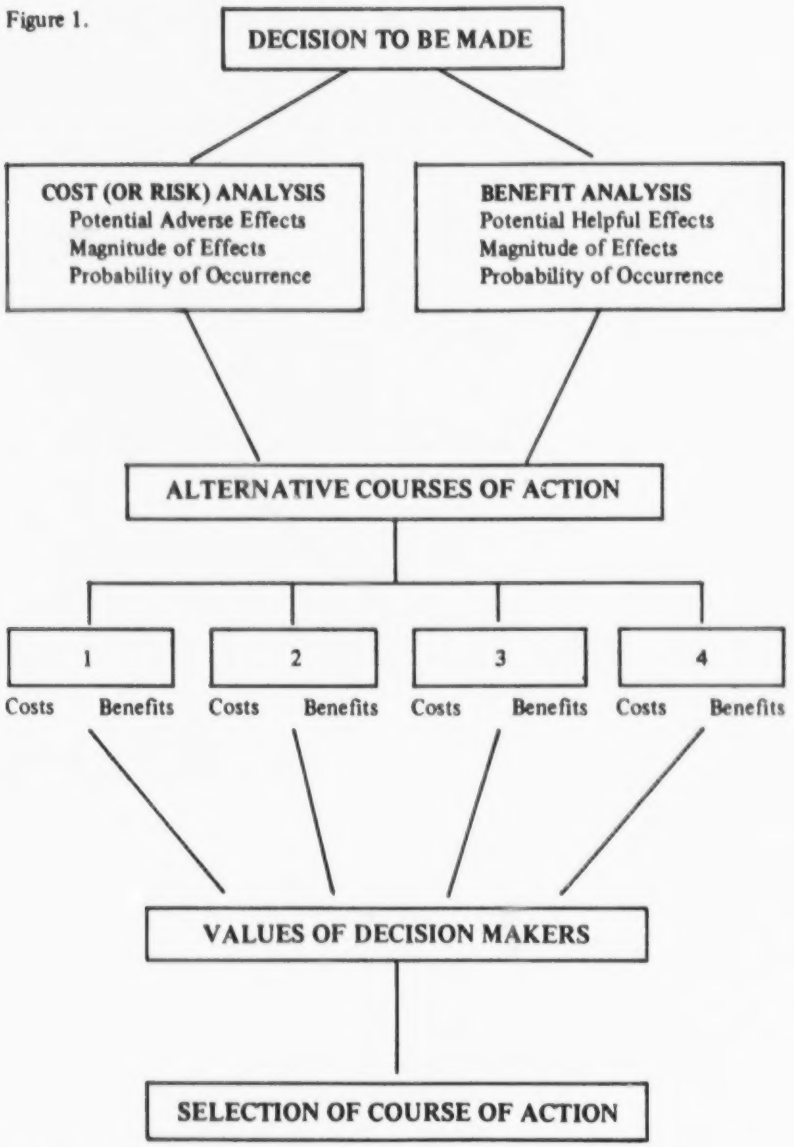
Appendix 11



From Science Instruction in Middle and Secondary Schools (p. 217) by A.T. Collette and E.L. Chiappetta, 1984, St. Louis, MO: Mosby. Copyright 1984 by Times Mirror/Mosby College Publishing.

Teaching about Science, Technology and Society

Figure 1.



From "Teaching About Science, Technology and Society at the Secondary School Level in the United States: An Educational Dilemma for the 1980s" (p. 21) by M. McConnell, 1982. In D. Layton (Ed.), Studies in Science Education, 9, East Yorkshire, UK: University of Leeds, Centre for Studies in Science Education. Copyright 1982 by Studies in Education Limited.

An NSTA Position Statement

Appendix 12

Recommended Standards for the Preparation and Certification of Teachers of Science at the Elementary and Middle/Junior High School Levels

SCIENCE PREPARATION FOR PRESERVICE ELEMENTARY TEACHERS

INTRODUCTION

Although science is generally recognized as a curriculum requirement in the elementary schools of the United States, the teaching of science is beset with problems. Significant numbers of elementary teachers feel unqualified in science and uncomfortable when they have to teach it (1). Too often, little time is devoted to science instruction and many teachers ignore it completely.

During the late 1970s, National Science Foundation case studies of elementary schools revealed a general de-emphasis of science. Stake and Easley summed up their observations by concluding:

> Although we found a few elementary teachers with a strong interest and understanding of science, the number was insufficient to suggest that even half of the nation's youngsters would have a single elementary school year in which their teacher would give science a substantial share of the curriculum and do a good job of teaching it (2).

Poor preservice teacher preparation is often cited as a prime contributor to the problems of science education at the elementary school level. State science supervisors and elementary school principals perceive inadequate teacher preparation in science as a serious problem (1). Teachers, too, blame their shortcomings on their preservice preparations. Many believe that their college or university programs did not adequately prepare them for the science teaching they are expected to do in their own elementary school classrooms(3). Colleges and universities are aware of the need for improvement. Recent National Science Teachers Association (NSTA) studies of leading teacher education institutions revealed that 50 percent or more felt that their programs for preparing preservice elementary teachers in science could be improved through increased emphasis on science content, science processes and methods, and science teaching techniques (4).

It must be noted that good guidelines for the preservice science education of elementary school teachers already exist. They were prepared more than a decade ago by the American Association for the Advancement of Science (AAAS) (5). While these guidelines are still relevant and valuable and should continue to be used, it appears that either many institutions failed to implement them, or slippage has occurred. Recent surveys conducted by NSTA (3, 4, 6) have disclosed serious deficiencies in the science preparation of elementary teachers. These deficiencies must be addressed if we wish to improve both the quantity and quality of science experiences for elementary school children.

Recommended Standards for Elementary Science Teachers

Standard I.a.
Science Content Preparation

All colleges and universities should require a minimum of 12 semester hours or 18 quarter hours of laboratory or field-oriented science including courses in each of these areas: biological science, physical science, and earth science.

Standard I.b.
Science Content Course for Elementary Teachers

These courses should be designed specifically to serve the needs of preservice elementary school teachers. They should (a) provide knowledge of science content selected for its application to elementary school classrooms; (b) increase skill in using the processes of science; and (c) develop positive attitudes toward science and science instruction at the elementary school level.

If student enrollment does not warrant separate courses in science content for preservice elementary teachers, the required science courses should reflect the special needs of these preservice teachers.

Standard II.a.
Science Teaching Methods

Preservice elementary teachers should be required to complete a minimum of one separate course of approximately three semester hours in elementary science methods. This course should be scheduled after the science content courses have been completed and just prior to student teaching.

Standard II.b.
Content of the Science Teaching Methods Course

The elementary science methods course should develop instructional skills designed to assist preservice teachers to teach science processes, attitudes, and content to elementary school children, grades K-6. The course should include experiences such as hands-on activities to promote process skill development, the selection of science content appropriate for the elementary school, the design of classroom environments that promote positive attitudes, the selection and use of a variety of instructional strategies and materials, and the development of techniques for evaluating pupil progress in science.

Standard III.
Field Experiences

Preservice elementary teachers should have opportunities throughout their undergraduate years to teach science to children in schools. These field experiences in science should begin with observations and tutoring and proceed through small and large group instruction. Student teaching must include experiences in planning and teaching science.

Standard IV.
Faculty Preparation

Faculty assigned to teach science content and methods courses for preservice elementary teachers should have the qualifications, experience, and interest to provide high-quality instruction. They should be as carefully screened and selected as those faculty members who are assigned courses in other academic majors.

Standard V.
Facilities, Equipment, and Materials

Preservice elementary teachers should be instructed in science laboratories and educational facilities that include equipment, instructional materials, and library holdings that promote science learning and exemplify outstanding school science programs.

Standard VI.
Professional Orientation

The professional orientation of preservice elementary teachers should include experiences that (a) instill positive attitudes toward science and science teaching, (b) foster an appreciation for the value of science in the total curriculum and in the lives of the children, and (c) develop a commitment to continue their education as teachers of science through reading, participating in professional organizations, and furthering education, including inservice experiences.

National Science Teachers Association, ©1983.

I. PREPARATION IN SCIENCE CONTENT

There appears to be universal agreement that elementary school teachers should have reasonable knowledge of science content. This content then becomes the reservoir from which they draw as they teach science to elementary school children. Unfortunately, preservice elementary teachers may be getting neither the quantity nor kind of science content they need.

A recent survey of colleges and universities having the largest numbers of teacher education graduates revealed serious deficiencies in the science content preparation of preservice elementary teachers (4). For instance, in half of these leading institutions, only 8 semester hours or less of science were required for persons preparing to teach science at the elementary school level—very close to the same number of hours required in the general education of *all* students, none of whom will be expected to teach science.

Only 18 percent of the institutions required elementary teacher candidates to complete science courses in all three major areas of science: biological science, physical science, and earth science. In most institutions, preservice elementary teachers could get by without taking courses in one or two of these areas, such as physical science or earth science, thereby leaving them woefully lacking in subject areas they will later be expected to teach in their own classrooms.

Only one-third of the institutions design their science courses specifically to meet the needs of elementary teacher candidates. The rest appear to give preservice teachers the same "dose" of science as majors in history,

art, business, or physical education. The result is that many teachers frequently complain that they see no relationship between the content and mode of instruction of their college courses and the science they are expected to teach. The AAAS Guidelines remind us that we should make an effort to relate the science topics that are taught to teachers to the science topics taught to children (5).

As part of its overall commitment to improve science education in the United States, NSTA recommends that the Recommended Standards on the previous page be recognized and implemented.

II. SCIENCE TEACHING METHODS

Science has many characteristics which distinguish it from other school subjects. The basic objectives of science instruction include teaching science process skills and attitudes as well as science content. Learning science process skills and developing scientific attitudes requires the use of activity-oriented, investigative teaching methods. These methods are different in kind and amount from the general methods of teaching elementary school subjects and can be taught most effectively in a separate methods course specifically for science.

Current research indicates that only 26 percent of the 50 states require a separate science methods course for elementary certification and 17 percent require no methods course at all (6). Another survey shows that colleges and universities usually exceed minimal state certification standards for methods courses. Ninety-four percent of the colleges and universities which produce the largest number of teacher education graduates require a separate science methods course to complete program requirements in elementary education (4). Findings from a related study of experienced elementary teachers in the field indicated that 79 percent had completed a separate science methods course. Eighteen percent had completed only a general methods course (3).

While the data clearly indicate that a separate course in science methods is usually required, opportunities still exist for preservice elementary teachers to take a general methods course or no methods course at all, thereby excluding science.

Further, there is a potential problem regarding the timing of the science methods course. Preservice teachers should have an opportunity to acquire a fundamental knowledge in the sciences before they learn about strategies for teaching it. The methods course in science should occur late in the preservice teacher's career, after the science content courses have been completed and just prior to student teaching.

III. FIELD EXPERIENCES

Field experiences with children in schools should be an essential part of programs preparing preservice elementary teachers. During the last decade, the number of field experiences has increased. More emphasis has been placed on observation/participation experiences throughout the undergraduate years. Unfortunately, because of the general de-emphasis on science at the elementary school level, science is often excluded from field experiences, and, in some cases, even from student teaching.

The techniques of science instruction are best learned through practice. Preservice elementary teachers must be afforded the opportunity to teach science to children throughout their college careers, preferably in a variety of schools at several different grade levels.

IV. FACULTY PREPARATION

Identifying who will teach science content and methods courses to preservice teachers is as important as identifying *what* they will teach. Institutions desiring to develop teacher education programs of quality cannot afford to permit less than well-qualified individuals to teach content and methods courses for preservice elementary teachers.

Each faculty member teaching content courses to preservice elementary teachers should have credentials comparable to those required for other science courses. Moreover, these courses should be assigned to faculty having the most interest in teacher preparation. They should not be assigned to less well-qualified personnel such as graduate assistants, who have little or no experience in science or science teaching.

Methods course teachers should also have had specific training and experience in the teaching of science, and should maintain a continuous association and involvement with elementary schools. Superior work in schools and with teachers must be recognized and rewarded in decisions regarding their retention, tenure, and promotion. In no way should the science methods experiences of preservice elementary teachers be given less emphasis than those of other academic areas.

V. FACILITIES, EQUIPMENT, AND MATERIALS

Science can best be learned in an atmosphere where students can investigate, explore, and discover. Getting a feeling for the nature of scientific inquiry is no less important for preservice elementary teachers than it is for those pursuing scientific careers. If preservice teachers are prepared in environments that invite and support curiosity, investigation, and inquiry, they are more likely to provide similar environments for their own pupils. Such environments must be rich science learning resources.

Instructional programs for the preparation of preservice elementary teachers of science should include laboratory equipment, instructional materials, and library holdings comparable to those used by practicing elementary teachers. Further, such programs should include regular budgetary allocations to ensure the acquisition of quality science education resources in quantities sufficient to guarantee hands-on experiences.

VI. PROFESSIONAL ORIENTATION

The pressures of teaching all subjects in self-contained classrooms has often relegated science to a less important

role—a role which is unacceptable in a world increasingly characterized by science and technology. Preservice teachers must have a knowledge of science content and skill in using science processes. They must exhibit scientific attitudes and demonstrate competence in using effective teaching methods. They must also develop an appreciation for the role of science in the total elementary curriculum and in the lives of the children.

Every effort must be made to instill in preservice elementary teachers positive attitudes toward science and science teaching. They must sense the joy of science and its value to the lives of the children they will teach. They must see science as an opportunity to learn how to ask significant questions, to seek relevant answers, to apply problem-solving skills to everyday life, to think rationally, to test ideas, to make decisions, to explore, to investigate, to try and fail, and try again.

Their preservice experiences in science should provide the foundation for life-long learning in science—a commitment to continue their education in science through reading, participation in professional organizations, and further education, including inservice experiences.

REFERENCES

1. Weiss, Iris R., *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education*. Washington, DC: U.S. Government Printing Office, March, 1978.

2. National Science Foundation, *The Status of Pre-College Science, Mathematics and Social Studies Educational Practices in U.S. Schools: An Overview and Summaries of Three Studies*. Washington, DC: U.S. Government Printing Office, July, 1978.

3. Donnellan, Kathleen M., *NSTA Elementary Teacher Survey on Preservice Preparation of Teachers of Science at the Elementary, Middle, and Junior High School Levels*. Washington, DC: National Science Teachers Association, March 1, 1982.

4. Mechling, Ken, *Survey Results. Preservice Preparation of Teachers of Science at the Elementary, Middle, and Junior High School Levels*, Washington, DC: National Science Teachers Association, March 1, 1982.

5. AAAS Commission on Science Education, *Preservice Science Education of Elementary School Teachers*. Washington, DC: American Association for the Advancement of Science, April, 1970.

6. Stedman, Carl, and Ken Dowling, *Data Summary and Discussion for State Requirements for Teacher Certification in Science Questionnaire*. Washington, DC: National Science Teachers Association, March, 1982.

MIDDLE/JUNIOR HIGH SCHOOL SCIENCE TEACHER PREPARATION

I. INTRODUCTION

It is axiomatic that our nation's well-being is directly related to the success or failure of its scientific and technological enterprises. The foundations of science and technology lie in our schools and are built on by our science teachers. It is here that the spark of interest is struck for future scientists and engineers. It is here that our young people learn to make wise decisions. It is here that many students turn on or off to science and technology. Too many of our students end their formal science education as early as the ninth grade. The fact that many science career choices are made during the early adolescent years makes it particularly important that middle school and junior high school science classes be taught by qualified teachers who have been specifically prepared to teach at these levels.

Current certification standards and practices in most states allow teachers, with either elementary certificates or secondary certificates, to interchangeably provide instruction for middle and junior high school students (1). Consequently, science teachers at these levels may have science preparations ranging from zero hours of science coursework to as much as a full major in one of the science disciplines. Further, where a science teaching methods course is taught, it is typically specified for either elementary or secondary teachers, not for middle/junior high school teachers. When we consider that there are more middle and junior high school science teachers than there are high school science teachers, the failure to provide the adequate preparation for middle/junior high school science teachers is unforgivable.

The Recommended Standards on the next page are intended to provide a framework for the establishment or improvement of programs designed to prepare science teachers who will work with early adolescents.

II. PREPARATION IN SCIENCE CONTENT

Science courses designed for the middle/junior high school generally include biological, earth, and physical sciences. The breadth of offerings and the significance of science instruction during the early adolescent years make it imperative that the middle/junior high school teacher have sufficient preparation in both science content and science teaching methods. The science courses required of middle/junior high school teachers should be designed to develop a) knowledge of science content applicable to middle/junior high school students, b) skill in using the processes of science, and c) positive attitudes toward the learning and teaching of science.

The nature of science and technology today also demands that the science teacher understand basic mathematic operations and applications of computer technology. Without this knowledge, many scientific problems cannot be solved nor can the benefits of computers as an instructional aid be fully utilized.

III. SCIENCE TEACHING METHODS

Since most states employ broad-field (several subject areas) certification in elementary schools and specific subject area certification in secondary schools, the methods courses in most universities relate to either elementary or secondary science instruction. A recent survey (2) showed that only 2 of the 45 responding teacher-training institutions had specific middle/ junior high school science teaching methods courses. Most institutions, 89 percent, required a secondary science methods course for prospective middle/junior high school science teachers. Because of the wide range of sciences taught at the middle/junior high

Recommended Standards for Middle/Junior High Science Teachers

Standard I.
Middle/Junior High Science Teacher Certification
Separate, specific middle/junior high school science teacher certification programs should be established. They should contain science content, methodology, field experiences, and professional orientation activities designed specifically for the middle/junior high school science teacher.

Standard II.a.
Science Content Preparation
A minimum of 36 semester hours of collegiate science instruction should be required of all preservice middle/junior high school science teachers. This coursework should include the major science disciplines of biology, earth science, and physical science, with at least 9 hours of biological or life science, 9 hours of physical science (physics and chemistry), and 9 hours of earth-space science. The remaining 9 hours would include electives from among the major science disciplines.

Standard II.b.
Support Content Preparation
The middle/junior high school science teacher should also have a minimum of 9 hours in mathematics and computer science instruction.

Standard III.a.
Science Teaching Methods Preparation
Middle/junior high school teachers should have a specific science teaching methods course.

Standard III.b.
Content of Science Teaching Methods Course
The methods course designed for middle/junior high school teachers should emphasize science curriculum development, appropriate instructional strategies and materials, techniques for evaluation of pupils and programs, and the application of recent research in the psychology and sociology of the early adolescent student as it relates to science instruction.

Standard IV.a.
Classroom Observation/Participation
Prospective middle/junior high school science teachers should have opportunities for classroom observation/participation in early adolescent science classes taught by competent teachers. Such experiences should be provided during each year of their preservice preparation program.

Standard IV.b.
Student Teaching/Internship
The culminating field experience for the preservice middle/junior high school science teacher should be an internship of one semester's or quarter's duration. There must be ample time and opportunity to plan and provide instruction for students in a middle/junior high school science classroom supervised by a competent science teacher.

Standard V.
College/University Science and Science Teaching Methods Faculty
The university/college faculty members selected to teach science and/or science teaching methods courses to preservice teachers should have professional preparation in these areas and be committed to the education of teachers of early adolescent children.

Standard VI.
Facilities, Equipment, and Materials
Preservice middle/junior high school science teachers should be instructed in science laboratories and educational facilities that include equipment, instructional materials, and library holdings that promote science learning and exemplify outstanding middle/ junior high school science programs.

Standard VII.
Professional Orientation
The middle/junior high school science teacher preparation program should provide experiences which will engender professional pride, dedication, and commitment to the early adolescent child and early adolescent instruction.

National Science Teachers Association, © 1983

school, the special curriculum materials available, and the nature of the early adolescent student, it is recommended that a methods course be taught specifically for teachers of early adolescents.

IV. FIELD EXPERIENCES AND STUDENT TEACHING

It is universally recognized that practical experiences provide invaluable learning opportunities for prospective teachers. Most states now require student teaching or internship for students during their final year of undergraduate preparation. Recently, emphasis has been placed upon observation/participation throughout the undergraduate program. These field experiences in science should begin with observation and proceed through tutoring and small and large group instruction. These experiences enable students to apply instructional theory directly, to develop instructional skills, to determine personal suitability for the teaching of science as a profession, and most important, to ascertain whether working with early adolescents is personally satisfying.

V. FACULTY PREPARATION

Identifying *who* will teach science content and methods courses to preservice teachers is as important as identifying *what* will be taught. Institutions desiring to develop

teacher education programs of quality cannot afford to permit less than well-qualified individuals to teach content and methods courses for preservice teachers.

Each faculty member teaching content course to preservice, middle/junior high school teachers should have credentials comparable to those required for other science courses. These courses should not be assigned to faculty members having little interest in teacher preparation, nor should they be assigned to less well-qualified personnel such as graduate assistants, who may have little preparation in the sciences and science education.

Likewise, science teaching methods instructors should have had specific training or experience at the middle/junior high school level. These instructors must maintain a continuous association and involvement with schools to remain in touch with the field and retain credibility.

VI. FACILITIES, EQUIPMENT, AND MATERIALS

If the preparation of preservice, middle/junior high school science teachers is to be of high quality, then library holdings, laboratory materials, teaching equipment, and instructional materials must be adequate, related to middle/junior high school science teaching, and funded appropriately.

VII. PROFESSIONAL ORIENTATION

The lack of specific undergraduate programs for the middle/junior high school science teacher has often produced a professional identity crisis. Commitment and allegiance to the teaching of early adolescents, and to the early adolescents themselves, may be lacking because teachers have been conditioned to aspire to high school or elementary instruction. Teacher education programs must address this problem by emphasizing the positive aspects of middle grade instruction in the sciences. Such a goal can be accomplished by providing prospective teachers with literature that describes the early adolescent student; giving them opportunities to observe and participate in student teaching in middle/junior high school classrooms; discussing with them the advantages of teaching early adolescent students; and encouraging them to attend professional meetings relating to this age group.

REFERENCES

1. Stedman, Carl, and Ken Dowling, *Data Summary and Discussion for State Requirements for Teacher Certification in Science Questionnaire*, Washington, DC: National Science Teachers Association, March, 1982.

2. Mechling, Ken, *Survey Results: Preservice Preparation of Teachers of Science at the Elementary, Middle, and Junior High School Levels, Washington, DC: National Science Teachers Association, March 1, 1982.*

Purpose and Development

In response to the growing concern about the quality of science teaching across the nation, the 1982-83 Standing Committee on Teacher Education of the National Science Teachers Association prepared this document. During the process of refining this material, several hundred organizations and individuals across the United States were sent drafts for their comments and recommendations. This final version was adopted unanimously as a position statement of the Association by the NSTA Board of Directors in April, 1983 in Dallas, Texas.

The standards recommended here represent a beginning, a first step toward improving science teacher education and certification at the elementary and middle/junior high school levels. The document proposes selected standards which, if implemented, could result in improved experiences for children.

These standards are intended to provide guidelines to leaders in colleges and universities, accreditation agencies, and state departments of education who are responsible for upgrading their programs to achieve minimal levels of quality in science preparation for preservice teachers of science. Recommendations for standards in teacher preparation at the high school level are under development and expected to be ready for consideration by the Board of Directors in April, 1984 at the NSTA National Convention in Boston.

Subcommittee on Teacher Education 1981-83
Kenneth R. Mechling, *Chairman*
Clarion University
Clarion, Pennsylvania

Stephen A. Henderson
Eastern Kentucky University
Richmond, Kentucky

Carlton H. Stedman
Austin Peay State University
Clarksville, Tennessee

NSTA Steering Committee on Teacher Education, 1981-83
Audrey Brainard
Betty M. Burchett
Kathleen M. Donnellan
Kenneth W. Dowling
Robert L. Fisher
Stephen A. Henderson
Kenneth R. Mechling
Otis J. Smith
Carlton H. Stedman
Marten Tafel
Gilbert Twiest

NSTA Standing Committee on Teacher Education, 1982-83
Kenneth R. Mechling
H. Prentice Baptiste
William R. Brown
Fred L. Fifer
Walter A. Cory, Jr.
Thomas C. Fitch
Donald L. Oakley
Lowell J. Bethel, *AETS*
Robert L. Fisher, *NCATE*

Additional Copies are available for a self-addressed, stamped envelope from:
NSTA Position Statement, Standards
NATIONAL SCIENCE TEACHERS ASSOCIATION
1742 Connecticut Avenue, N.W.
Washington, D.C. 20009

Copyright 1983 by the National Science Teachers Association.

Appendix 13

NSTA Position Statement on Science–Technology–Society: Science Education for the 1980s

Preamble

Science and technology influence every aspect of our lives. They are central to our welfare as individuals and to the welfare of our society. All around us are examples of the importance of science and technology for production of food, water, shelter, clothing, medicines, transportation, and various sources of energy. There are an increasing number of science- and technology-related societal problems as well as increasing societal benefits. Science and technology are central to our personal and cultural welfare *and* to many societal problems. We must insure appropriate science education for all citizens.

However, the quantity and quality of science education for all people are not commensurate with the status of science and technology in society. When one would expect budgets, time spent on science-related subjects, and support for science education to be increasing, they are decreasing. At the same time these factors are declining, societal problems continue to require an understanding of science and technology. The burden of response rests heavily upon the shoulders of *all* persons associated with science endeavors—scientists, engineers, classroom teachers, other educators, and school administrators. Many of the problems we face today can be solved only by persons educated in the ideas and processes of science and technology. A scientific literacy is *basic* for living, working, and decision making in the 1980s and beyond.

There is a crisis in science education. The following science-technology-society problems demand immediate attention:

- understanding of science and technology are central to our personal and national welfare, yet public appreciation of science education has declined;
- increasing numbers of individual and societal problems which have an impact on the quality of life are related to science-generated technology;
- as the impact of science and technology on society has increased, the support for science education has decreased;
- compared to its recent past the United States has fallen behind in the production of scientific and technological goods and services; and
- women, minorities, and handicapped persons are underrepresented in nearly all professional and technical roles in science and technology.

Declaration

The goal of science education during the 1980s is to develop scientifically literate individuals who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision making. The scientifically literate person has a substantial knowledge base of facts, concepts, conceptual networks, and process skills which enable the individual to continue to learn and think logically. This individual both appreciates the value of science and technology in society and understands their limitations.

The attributes listed below help to describe a scientifically literate person. Each attribute should be thought of as describing a continuum along which the individual

may progress. The progress of the individual's science education should be equated with progress along this continuum.

The scientifically and technologically literate person:

- uses science concepts, process skills, and values in making responsible everyday decisions;
- understands how society influences science and technology as well as how science and technology influence society;
- understands that society controls science and technology through the allocation of resources;
- recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;
- knows the major concepts, hypotheses, and theories of science and is able to use them;
- appreciates science and technology for the intellectual stimulus they provide;
- understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories;
- distinguishes between scientific evidence and personal opinion;
- recognizes the origin of science and understands that scientific knowledge is tentative and subject to change as evidence accumulates;
- understands the applications of technology and the decisions entailed in the use of technology;
- has sufficient knowledge and experience to appreciate the worthiness of research and technological development;
- has a richer and more exciting view of the world as a result of science education; and
- knows reliable sources of scientific and technological information and uses these sources in the process of decision making.

Recommendations for K-12 Grade Levels

Elementary School Science

Science should be an integral part of the elementary school program. It should be used to integrate, reinforce, and enhance the other basic curricular areas so as to make learning more meaningful for children.

A carefully planned and articulated elementary science curriculum should provide daily opportunities for the sequential development of basic physical and life science concepts, along with the development of science process and inquiry skills.

Elementary science should provide opportunities for nurturing children's natural curiosity. This helps them to develop confidence to question and seek answers based upon evidence and independent thinking. Children should be given an opportunity to explore and investigate their world using a hands-on approach, with instructional materials readily available.

The focus of the elementary science program should be on fostering in children an understanding of, an interest in, and an appreciation of the world in which they live.

Middle/Junior High School Science

The middle/junior high school science curriculum should be designed to accommodate the needs and learning styles of the early adolescent. Students should be provided with daily opportunities to explore science through reading, discussion, and direct learning experiences in the classroom, laboratory, and field.

Middle/junior high school science should contribute to the development of scientifically literate persons and not simply prepare them for the next science course. National studies have shown that often middle/junior high school science is designed to prepare students for high school biology with no emphasis on physical science. In addition, studies show that fewer than one half of the junior high students going on to high school take chemistry and physics. Therefore, it is imperative that an important

thrust of middle/junior high school science be toward the physical and Earth sciences.

Middle/junior high school students should continue to develop science process skills and content. Middle/junior high school science should emphasize the *application* of both skills and content to the students' personal life situations and enable students to begin examining societal issues that have a scientific and technological basis. Middle/junior high school students need to *apply* what they have learned soon after their instruction to insure the lasting value of the experience.

High School Science

The high school science curriculum should enable students to further develop their scientific and technological literacy. Courses incorporating well-designed laboratory and field work help to meet this need.

A balanced core of two years of science should be required of *all* students, consisting of one year of life science and one year of physical science—both taught in a science-technology-society context. The courses should provide students with opportunities to develop skills in identifying science-based societal problems and in making decisions about their resolution.

Students interested in exploring or preparing for careers in science, engineering, or technical fields should have the opportunity to take additional discipline-based courses in advanced biology, chemistry, physics, and Earth sciences. These courses should be planned and sequenced to take advantage of the students' increasing command of mathematics.

Time on science learning

- Lower elementary level (grades K-3): a minimum of 1½ hours/week of science should be required.
- Upper elementary level (grades 4-6): a minimum of 2½ hours/week of science should be required.
- Middle/junior high school level (grades 7-9): a minimum of 1 hour/day for at least 2 full years of science should be required of all students.
- Senior high school level (grades 10-12): a minimum of 1 hour per day for 2 full years of science should be required. The courses should represent a balance of physical and life sciences.

Emphasis on programs for all students

- In elementary, middle, junior, and senior high school grades, science education programs should provide basic concepts for all students. Opportunities should be available for students with diverse interests and commitments, including students with exceptional interests and talents in science.

Emphasis on science education for the adult general population

- Schools should provide educational opportunities in science for all the adult population in their community.
- Colleges, universities, and national organizations should increase emphasis on science education for adults through public lectures and seminars.
- The important contributions of out-of-school education programs such as museums, TV, planetariums, and zoos should be recognized and utilized by all those involved.

Emphasis on the professional development of science teachers through inservice opportunities

- Colleges, universities, and other agencies should develop teacher education and inservice education programs that are consistent with this policy statement.
- School districts should provide opportunities, encouragement, and recognition for teachers who maintain a high level of professional competence.

Emphasis on laboratory and field activities

- Elementary level laboratory and field activities should stress the development of basic inquiry skills.
- Middle/junior high school level laboratory and field activities should stress the application and extension of inquiry skills as a means of obtaining knowledge and resolving problems.
- High school level laboratory and field activities should emphasize not only the acquisition of knowledge, but also problem solving and decision making.

Science instruction matches students' cognitive, physical, social, and emotional development

- Schools should provide objectives, content, and instructional strategies that are appropriate to the student's stage of mental, moral, and physical development.
- Varying strategies and materials should be provided at all grades to accommodate students with various levels of learning skills and mental development.

Emphasis on science-related societal issues

- Elementary level: a minimum of 5 percent of science instruction should be directed toward science-related societal issues.
- Middle/junior high school level: a minimum of 15 percent of science instruction should be directed toward science-related societal issues.
- Senior high school level: a minimum of 20 percent of science instruction should be directed toward science-related societal issues.

This NSTA Position Statement was adopted unanimously by the Board of Directors in 1982.

From Science Teaching--A Profession Speaks (1983 NSTA Yearbook) (pp. 109-112), F.K. Brown and D.P. Butts (Eds.), 1983, Washington, DC: National Science Teachers Association. Copyright 1983 by the National Science Teachers Association.